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SSTAC/ARTS REVIEW OF THE DRAFT INTEGRATED TECHNOLOGY PLAN (ITP)

Volume IV: June 26-27

Materials and Structures

Briefings from the
June 24-28, 1991 Meeting
McLean, Virginia

National Aeronautics and Space Administration
Office of Aeronautics, Exploration and Technology
Washington, D.C. 20546

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SSTAC/ARTS REVIEW OF THE DRAFT ITP
McLean, Virginia
June 24-28, 1991

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Materials and Structures

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INTEGRATED TECHNOLOGY PLAN
FOR THE CIVIL SPACE PROGRAM

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OVERVIEW PRESENTATION
TO
SSTAC/ARTS REVIEW COMMITTEE

Samuel L. Venneri
Director
Materials and Structures Division

JUNE 25, 1991

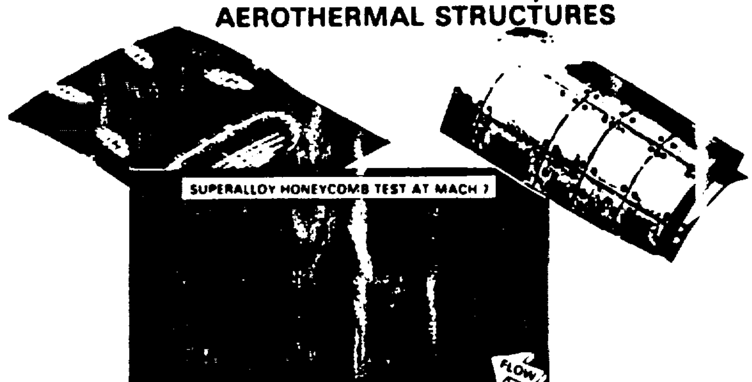
OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

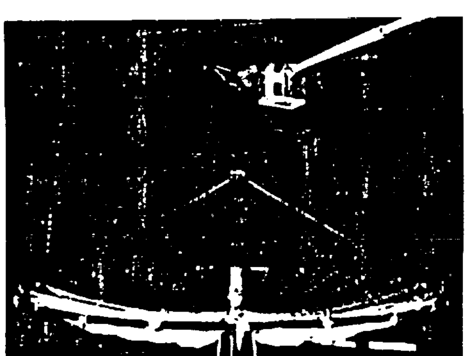
WASHINGTON, DC 20546

MATERIALS AND STRUCTURES

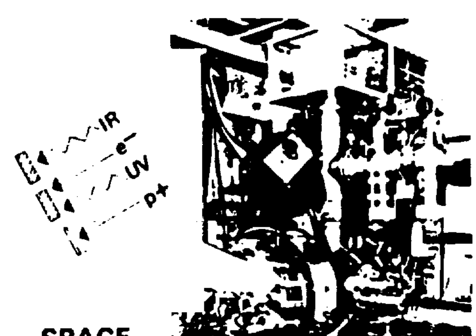
STRUCTURAL CONCEPTS

AEROTHERMAL STRUCTURES





DYNAMICS OF FLEXIBLE STRUCTURES



SPACE DURABLE MATERIALS

MATERIALS AND STRUCTURES FY 1993 ITP PROGRAM

BASE R&T

MATERIAL SCIENCE

- MATERIAL SYNTHESIS
- *COMPUTATIONAL MATERIALS*
- COMPUTATIONAL CHEMISTRY
- *OPTICS*
- POWER & PROPULSION MAT'LS.

SPACE ENVIRONMENTAL EFFECTS

- DEBRIS PROTECTION
- SPACE ENVIRONMENTAL EFFECTS
- SPACECRAFT MATERIALS

AEROTHERMAL STRUCTURES & MATERIALS

- THERMAL PROTECTION SYSTEMS
- *ARCJET RESEARCH*
- *HEAVY LIFT LAUNCH*
- HOT STRUCT./INTEGRATED DESIGN

SPACE STRUCTURES

- STRUCTURAL CONCEPTS
- *SPACE MECHANISMS*
- *SPACE WELDING & BONDING*
- SPACE CONSTRUCTION
- NDE/NDI

DYNAMICS OF FLEXIBLE STRUCTURES

- ADVANCED TEST TECHNIQUES
- ADAPTIVE STRUCTURES
- *SPACE DYNAMIC ANALYSIS*
- *VIBRATION & ACOUSTIC ISOLATION*

FOCUSED PROGRAMS

SCIENCE

- SAMPLE ACQUISITION, ANAL. & PRESER.
- TELESCOPE OPTICAL SYSTEMS
- MICRO-CSI

TRANSPORTATION

- ETO STRUCTURES & CTRYOTANKS
- TRANSFER VEHICLE STRUCTURES & CRYO.

EXPLORATION

- RADIATION PROTECTION
- IN-SITU RESOURCE UTILIZATION
- SURFACE HABITATS & CONSTRUCTION
- ARTIFICIAL GRAVITY
- (POWER BEAMING)

PLATFORMS

- PLATFORM-CSI
- STRUCTURES
- NDE/NDI
- MATERIALS & SPACE ENVIRON. EFFECTS

OPERATIONS

- IN-SPACE ASSEMBLY & CONSTRUCTION

GENERIC HYPERSONICS (BASE R&T)

MATERIALS AND STRUCTURES BASE R&T FUNDING

OAET

FY 1991 TOTAL: $19400 K NET: $11350 K (INCLUDES $2540 K IN GENERIC HYPERSONICS)	PERCENT OF FY 1991 NET	FY 1992 TOTAL: $20930 K NET: $11350 K (INCLUDES $2640 K IN GENERIC HYPERSONICS)	PERCENT OF FY 1992 NET
MATERIAL SCIENCE $1940 K	17.1	MATERIAL SCIENCE $2160 K	19.0
SPACE ENVIRONMENTAL EFFECTS $2220 K	19.6	SPACE ENVIRONMENTAL EFFECTS $1330 K	11.7
AEROTHERMAL STRUCTURES AND MATERIALS $3110 K	27.4	AEROTHERMAL STRUCTURES AND MATERIALS $3110K	27.4
SPACE STRUCTURES $1190 K	10.5	SPACE STRUCTURES $1790 K	15.8
DYNAMICS OF FLEXIBLE STRUCTURES $350 K	3.1	DYNAMICS OF FLEXIBLE STRUCTURES $320 K	2.8

TECHNOLOGY PLAN FOR THE CIVIL SPACE PROGRAM

WORK BREAKDOWN STRUCTURE

OAET

SPACE SCIENCE TECHNOLOGY PROGRAM

- **SCIENCE SENSING (Remote)**
  - Direct Detectors
  - Submillimeter Sensing
  - Laser Sensing
  - Active Microwave Sensing
  - Passive Microwave Sensing
  - Sensor Electronics and Processing
  - Optoelectronics Sensors
- **OBSERVATORY SYSTEMS**
  - Telescope Optical Systems
  - Coolers and Cryogenics
  - Micro-Precision CSI
  - Sensor Optics
  - Precision Instrument Pointing
- **IN SITU SCIENCE**
  - Sample Acq. Analysis & Preservation
  - Surface Science Rovers
  - Probes and Penetrators
- **SCIENCE INFORMATION**
  - Data Visualization
  - Data Archiving and Retrieval
- **TECHNOLOGY FLIGHT EXPTS**
  - TBD

TECHNOLOGY PLAN FOR THE CIVIL SPACE PROGRAM

WORK BREAKDOWN STRUCTURE

OAET

TRANSPORTATION TECHNOLOGY PROGRAM

- **EARTH-TO-ORBIT TRANSPORTATION**
  - Earth-to-Orbit Propulsion
  - ETO Vehicle Structures & Materials
  - Earth-to-Orbit Vehicle Avionics
  - Low-Cost Commercial Transport
- **SPACE TRANSPORTATION**
  - Advanced Cryogenic Engines
  - Transfer Vehicle Structures & Cryo Tankage
  - Nuclear Thermal Propulsion
  - Transfer Vehicle Avionics
  - Nuclear Electric Propulsion
  - Autonomous Landing
  - Aeroassist (Aerobraking)
  - Autonomous Rendezvous & Docking
  - Cryogenic Fluid Systems
- **TECHNOLOGY FLIGHT EXPTS**
  - Aeroassist Flight Experiment
  - SEPS Flight Experiment
  - Cryogenic Orbital Nitrogen Expt (CONE)

TECHNOLOGY PLAN FOR THE CIVIL SPACE PROGRAM

WORK BREAKDOWN STRUCTURE

OAET

EXPLORATION TECHNOLOGY PROGRAM

- **AUTOMATION AND ROBOTICS**
  - Space Nuclear Power
  - Mobile Surface Systems
  - High Capacity Power
  - Surface Habitats and Construction
  - Surface Power & Thermal Management
  - Laser-Electric Power Beaming
  - In Situ Resource Utilization
- **INFORMATION & COMMUNICATIONS**
  - Regenerative Life Support
  - Extravehicular Activity Systems
  - Radiation Protection
  - Exploration Human Factors
  - Artificial Gravity
  - Medical Support Systems
- **TECHNOLOGY FLIGHT EXPTS**
  - TBD

TECHNOLOGY PLAN FOR THE CIVIL SPACE PROGRAM

WORK BREAKDOWN STRUCTURE

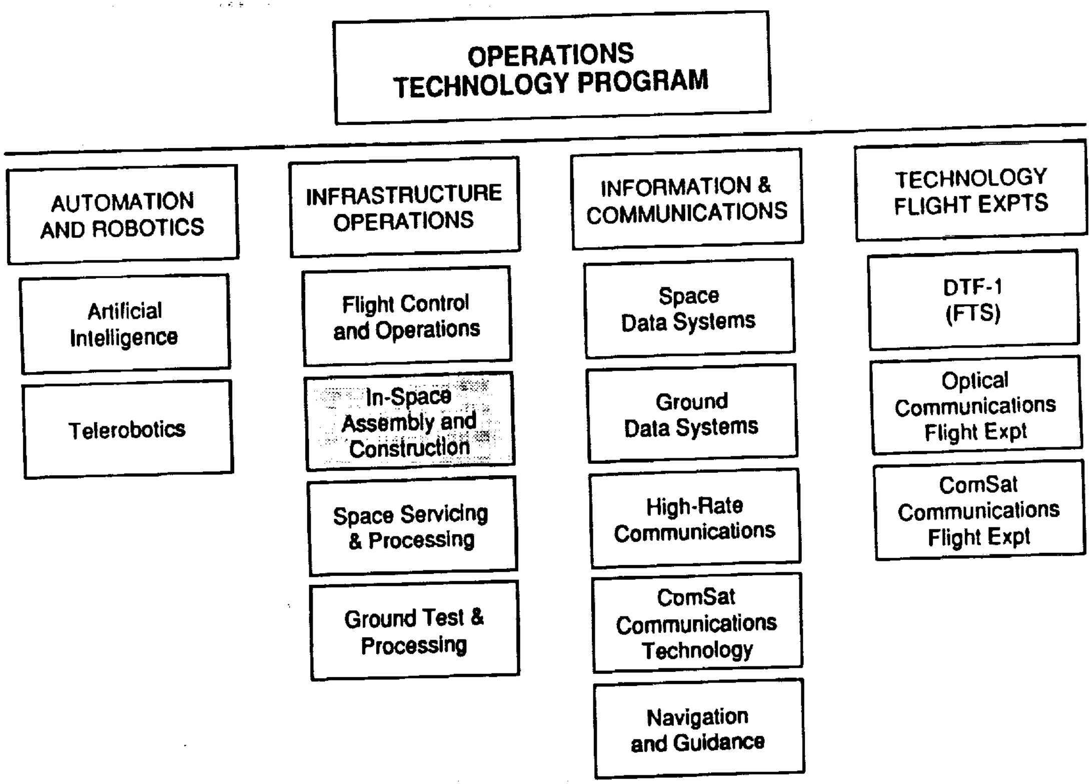
OAET

SPACE PLATFORMS TECHNOLOGY PROGRAM

- **EARTH-ORBITING PLATFORMS**
  - Power and Thermal Management
  - Platform Structures & Dynamics
  - Platform NDE/NDI
  - Platform Materials & Environmental Effects
  - Platform Controls
- **SPACE STATIONS**
  - Zero-Gravity ECLSS
  - Zero-Gravity Advanced EMU
  - Station-Keeping Propulsion
  - Advanced Refrigerator Systems
- **DEEP-SPACE PLATFORMS**
  - Spacecraft Power and Thermal Mgt
  - Spacecraft On-Board Propulsion
  - Spacecraft GN&C
- **TECHNOLOGY FLIGHT EXPTS**
  - Orbital Debris Experiment

WORK BREAKDOWN STRUCTURE

OAET



PROPOSED AUGMENTATION OVER FY 92 PFP RUNOUT

(REAL YEAR DOLLARS)

FISCAL YEAR	93	94	95	96	97	TOTAL
CURRENT RUNOUT ($K)*	24200	25300	26500	27700	28900	106100
PLANNED AUGMENTATION ($K)	4000	10300	14300	16700	20500	65800
MATERIAL SCIENCE	**900**	**2900**	**4200**	**4650**	**5700**	**18350**
COMP. MATERIALS	200	400	500	550	700	2350
COMP. CHEM.	0	600	800	850	1000	3250
OPTICS	700	1400	2100	2400	3000	9600
POWER & PROP. MAT.	0	500	800	850	1000	3150
SPACE ENVIRON. EFFECTS	**1050**	**1900**	**2600**	**3000**	**4050**	**12600**
DEBRIS PROTECTION	200	400	500	600	750	2450
SEE	450	900	1300	1500	2000	6150
SPACECRAFT MATERIALS	400	600	800	900	1300	4000
AEROTHERMAL STRUCT. & MAT.	**550**	**1800**	**2400**	**2850**	**3400**	**11000**
THERMAL PROTECTION SYSTEMS	350	700	800	1000	1200	4050
ARCJET RESEARCH	200	500	600	650	700	2650
HEAVY LIFT LAUNCH	0	400	700	800	900	2800
HOT STRUCT./INTEGRATED DESIGN	0	200	300	400	600	1500

* Includes $2.5 M from CSI to Base R&T in FY93. Does not include one time $4 M addition for LDEF in FY93

PROPOSED AUGMENTATION

	93	94	95	96	97	TOTAL
SPACE STRUCTURES	**1100**	**2200**	**3100**	**3650**	**4300**	**14350**
CONCEPTS & SPACE CONST.	400	800	1200	1500	1800	5700
SPACE MECHANISMS	300	500	700	800	900	3200
SPACE WELDING & BONDING	100	200	300	350	500	1450
NDE/NDI	300	700	900	1000	1100	4000
DYNAMICS OF FLEXIBLE STRUCT.	**400**	**1500**	**2000**	**2550**	**3050**	**9500**
ADVANCED TEST TECHNIQUES	0	400	600	700	800	2500
ADAPTIVE STRUCTURES	200	500	600	750	900	2950
SPACECRAFT DYNAMIC ANALYSIS	0	200	300	400	450	1350
VIBRATION & ACOUSTIC ISOLATION	200	400	500	700	900	2700
SPECIAL LDEF AUGMENTATION	**4000**	-	-	-	-	**4000**
TOTAL SPACE BASE R&T	**32200**	**35600**	**40800**	**44400**	**49400**	**175900**
GENERIC HYPERSONICS (SPACE)*	**(2640)**	**CONT.**				

*Separately funded and advocated through Aero-space Plane (NASP) Directorate. Included in baseline run out.

BASE R&T AUGMENTATION PRIORITY

	PROGRAM ELEMENT	5-YEAR AUGMENTATION ($K)
1	*OPTICS*	9600
2	SPACE ENVIRONMENTAL EFFECTS	6150
3	SPACECRAFT MATERIALS	4000
4	STRUCTURAL CONCEPTS & SPACE CONSTRUCTION	5700
5	*SPACE MECHANISMS*	3200
6	*NDE/NDI (SPACE STRUCTURES)*	4000
7	THERMAL PROTECTION SYSTEMS	4050
8	*ARCJET RESEARCH*	2650
9	DEBRIS PROTECTION	2450
10	*VIBRATION AND ACOUSTIC ISOLATION*	2700
11	ADAPTIVE STRUCTURES	2950
12	*COMPUTATIONAL MATERIALS*	2350
13	*SPACE WELDING AND BONDING*	1450
14	SPACE POWER AND PROPULSION MATERIALS	3150
15	COMPUTATIONAL CHEMISTRY	3250
16	*HEAVY LIFT LAUNCH*	2800
17	ADVANCED DYNAMICS TEST TECHNIQUES	2500
18	HOT STRUCTURES/INTEGRATED DESIGN	1500
19	*SPACECRAFT DYNAMIC ANALYSIS*	1350

TECHNOLOGY PERSPECTIVE
SPACE MATERIALS

1980's

- Composites
  - Application of aircraft composites
    - Microcracking
    - Moisture expansion
    - Thermal hysteresis
    - Residual stresses
- Structures
  - Large erectable/deployable truss structures
  - Low precision reflectors
- Films and coatings
  - Screening for AO resistance
  - Transparent polyimide films
  - Large area anodizing of Al

1990's and Beyond

- Composites
  - Development of new space tailored composites
    - New resins (cyanates)
    - Ultra-high modulus fibers
    - Innovative processing (low residual stress)
    - Smart materials
- Structures
  - High precision optical benches
  - Large lightweight high precision reflectors
  - Deployable/rigidizing materials and structures
- Films and coatings
  - Space tailored polymers
  - Inorganic composites/coatings

TECHNOLOGY PERSPECTIVE
SPACE MATERIALS (CONT.)

1980's

- Space environmental exposure/ simulation
  - Single parameter simulation or sequential exposure
  - Characterization/fundamental understanding
  - Radiation effects on materials
  - Single parameter environment/ materials modeling
  - 1st generation flight experiments
    - STS-3, 5, 8
    - LDEF

1990's and Beyond

- Space environmental exposure/ simulation
  - Combined exposures
    - e+, p+, UV, ΔT
    - AO, UV, ΔT
    - AO, micrometeoroids, ΔT
  - Next generation flight experiments
    - EOIM 3 (Atomic oxygen)
    - TDMX-2011 (Space Station)
    - "Benchmark"
  - Materials certification test methodology
  - Radiation shielding for humans
  - Life prediction modeling

TECHNICAL PERSPECTIVE SPACE STRUCTURES

1980's "ERA OF SPACE STATION'	1990's And Beyond "ERA OF SPACE SCIENCE AND EXPLORATION"
• Flat Trusses/Equal Length Struts	• Doubly- Curved Trusses/Unequal Strut Lengths, High Precision
• Design Methodology for Near-Earth Environment (LEO, GEO)	• Design Methodology for Deep Space Environment (GEO, Lunar and Mars)
• Erectable Space Station Truss Structure	• Complex Modular Structures, Joining/Welding and Precision Erectable/Deployable
• Space Station Pressure Vessel Structures	• Lightweight Lunar Habitats and Construction Methods
• Conventional Aluminum Design Concepts - Conventional Manufacturing	• Advanced Alloys and Composites for Low-Cost Fabrication, e. g., Gr/Ep Shells, Superplastic Forming, etc.
• EVA Manual Assembly - Low Mass Components and Ease of Construction	• Robotic Assembly - Precision Structures and Large Mass Manipulation, Integrated Utilities
• Large Antennae - Deployable Concepts, Low Frequency (<30 GHz) and Lightweight Submillimeter Telescopes	• Large Precision Antennae (30-100GHz) and Telescopes (RF Thru UV/Visible) - Complex Shape Control

TECHNOLOGY PERSPECTIVE SPACE STRUCTURAL DYNAMICS

1980's	1990's And Beyond
• Structural Dynamics - Uncoupled Rigid Body Dynamics and Linear Control	• Integrated Controls/Structures Interaction - Nonlinear Coupled Behavior
• Conventional Aerospace Material Systems Used for Tailoring Spacecraft Structural Dynamics - Metals Design Data Base - Uniform Properties	• "Smart" Material Systems Integrated Into Optimized Structural Dynamics and Control - Active Members - Embedded Sensors/Actuators
• Ground-Based System ID Methodology for Structural Verification	• On-Orbit System ID for Final Verification of Large Flexible Structures
• Capability for Linear, Small Deflection Dynamics of Space Structures	• Capability to Predict Behavior & Performance for Large Motions of Complex Articulating Structures
• Analysis and Ground-Based Testing Methodology for Spacecraft Qualification - Component Level Testing - Scale Model Tests - Full-Scale Behavior From Sub-Component Analysis and Synthesis	• New Qualification Methodology for Large Complex Space Structures - Reliable Full-Scale Analysis and Design Optimization Methods - Adaptive Structures - Full-Scale On-Orbit Testing

TECHNOLOGY PERSPECTIV E
AEROTHERMAL MATERIALS AND STRUCTURES

1980's

- Uncoupled Fluid, Thermal, Structural Vehicle Analysis and Design
- Combined Thermal and Mechanical Load Testing Capability
- High Temperature, Flow Test Facilities for Shuttle Re-entry (1000-25,000 BTU/lb)
- Rigid and Flexible Shuttle TPS Insulation Systems (1000-2500°F)
- Insulated Aluminum Structural Concepts
- Carbon-Carbon Material System with Limited-Use Coatings for Nonstructural Applications
- Applications Using Isotroptic, Monolithic Metallics and Refractory Material Systems (Superalloys, Ti, Intermetallics)

1990's And Beyond

- Integrated Fluid-Thermal-Structural Vehicle Analysis and Design Optimization
- Integrated Thermal, Mechanical and Cryogenic Complex Load Environment Simulation Test Capability
- High Temperature, Flow Facilities for High Enthalpy Earth Re-Entry (Aerobrake - 20,000-50,000 BTU/lb)
- Advanced Composite TPS Material Concepts (3000-5000°F)
- Integrated Insulated and Hot Structures Design Concepts
- Carbon-Carbon Material and Tailored Coating Systems for Primary Load-Carrying Structures
- Applications Using Fiber Reinforced Metal Matrix Composites and Refractory Composites (Gr/MMC, Advanced Intermetallic Composites)

R&T Base - 506-43

MATERIALS and STRUCTURES

$19.5 M (Gross FY91)

PROGRAM CONTENT

- Effects of the Space Environment on Materials and Structures
- Development of Space Durable Materials
- High Temp. Materials for Power and Propulsion
- Advanced Space Structural Concepts and Analysis/Design Methods
- Automated Space Construction
- Materials and Concepts for Hot Structures and TPS
- Tribology
- Adaptive Structures and Structural Dynamics Test Methodology

CENTERS: LaRC, ARC, LeRC, JPL, (JSC, GSFC)

RESOURCE INFORMATION

FUNDING	NET ($M)
FY-90	12.8
FY-91	11.3
FY-92	11.3

MANPOWER (FY-91 EST.) = 169

MAJOR FACILITIES:
8' HTT - LaRC
Arc Jets - ARC
Flt. Loads Research Fac. - DFRF
Liquid Hydrogen Structural Test Fac. ($18.0M FY91 CofF) - DFRF

PAYOFF

- Increased Life of Spacecraft Structures and Systems (Materials, Lubricants, NDE/NDI)
- Higher Temperature (More Durable & Efficient) Power and Propulsion Systems
- 25% Lighter, Higher Temperature TPS (>3800 F)
- Methods for Reduced EVA Construction and Structures with 50% Reduced Mass and Volume

DELIVERABLES

- Polymer Film for Gamma Ray Telescope - FY91
- Toughened (X100) Ceramic TPS Coating - FY91
- High Strength C-C Material - FY91
- Demonstrate Automated Assembly of a Planer Reflector - FY91
- 1800 F Flexible TPS - FY92
- 10-year Life Lubricant - FY93-95

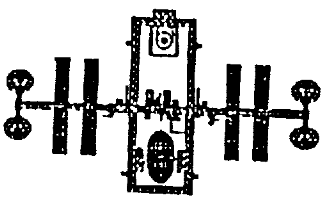
MAJOR CHANGES 90-91

- Space Environmental Effects Program Focused on LDEF Analysis
- Increased Emphasis on High Energy TPS (e.g. Planetary, earth Entry, Ablators)
- Increased Emphasis on Test Methods for Cryogenic Tankage

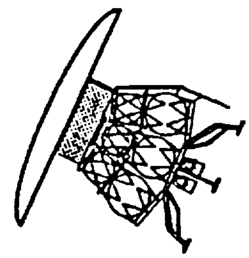
MAJOR CHANGES 91-92

- Increased Emphasis on Adaptive Structures and Smart Materials Directed Toward Controlled Processing and NDE/NDI
- (Need to Upgrade Arc Jet Capacity to 300MW - FY96 CofF)

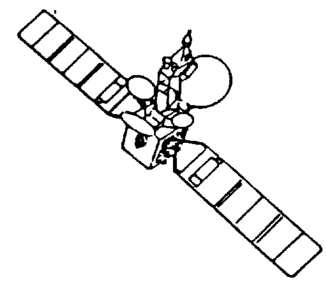
MISSIONS PROVIDING SPACE MATERIALS TECHNOLOGY FOCUS



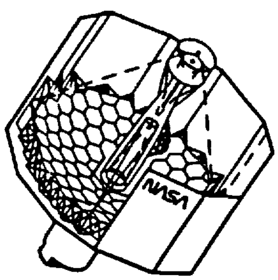
Space Station



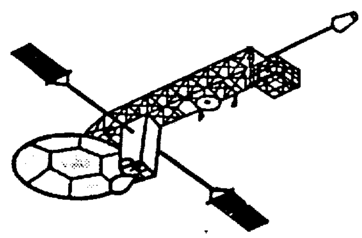
Lunar and Mars transfer vehicles



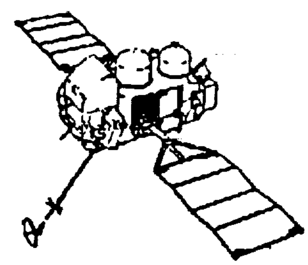
Communications satellites



Astrophysics missions



Mission to planet earth



Science missions

SPACE MATERIALS AND STRUCTURES

RM 500.0

THRUST(S) SUPPORTED

- Breakthrough
- Space Station, Science, Transportation

PROGRAM CONTENT

- Material Synthesis and Characterization
  - Computational Chemistry
  - Polymers for Coatings, Adhesives and Matrices
  - High Temp. Materials for Power & Propulsion
- NDE/NDI
- Tribology

PAYOFF

- Long-Life (>10yr) Space Mechanisms
- On-Orbit NDE/NDI for SSF and EOS
- Long-Life Power System Hot Section
- Tailored Polymers With +50% Life

DELIVERABLES

- Polymer Film for Gamma Ray Telescope Reflector - 1991
- Feasibility of Composite HTS - 1993
- Long-Life Lubricant (>10 yr) - 1993-1995
- On-Orbit NDE/NDI for SSF and EOS - 1993-1995

MATERIALS & STRUCTURES

(R&T Base)

MATERIAL SCIENCE

17.1 % of R&T Base

$11,350K (FY91)

CENTERS: LaRC, LeRC; JPL, ARC

RESOURCE INFORMATION

FUNDING	NET ($K)
FY-90	2660
FY-91	1940
FY-92	2160

MANPOWER (FY-91 EST.) = 41

MAJOR FACILITIES: None

MAJOR CHANGES 90-91

Increased Focus on Computational Analysis of Materials and Processes

MAJOR CHANGES 91-92

Re-Balancing Toward Spacecraft and Vehicle Applications

New Focus on "Smart Materials" Directed Toward Controlled Processing and NDE/NDI

THRUST(S) SUPPORTED

- Space Science
- Transportation

OBJECTIVE:

Develop computational methods to predict and simulate the behavior of materials during processing
- High temperature materials
- Advanced polymers

PAYOFF

Processing methods optimized to produce structural materials with desired properties

Processes with near-optimal yield

Reduced material development time

Reduced experimental costs

PRODUCTS (FY 1993 - FY 1996)

FY94: Accurate CVD process modeling

FY95: Optimized CVD process for SiC fibers

FY96: Processing models for high performance polymers

MATERIALS & STRUCTURES

(R&T Base FY 1993 Augmentation)

MATERIAL SCIENCE

COMPUTATIONAL MATERIALS

RATIONALE

Material processes are controlled by complex interaction of many parameters

Experimental methods cannot economically determine material processing sensitivities to parameter interactions

Advanced computational methods to be developed under this effort will enable accurate modeling of complex multi-disciplinary processes

(Complements Computational Chemistry)

CENTERS

LeRC, LaRC

AUGMENTATION	TOTAL ($K)
FY 1993	500
FY 1994	750
FY 1995	1000
FY 1996	1200
FY 1997	1400

CofF: None

MATERIAL SCIENCE

COMPUTATIONAL MATERIALS

OAET — MATERIALS & STRUCTURES

CURRENT PROGRAM

- LeRC: Small effort under microgravity research

  Seed activity for process modeling of CVD production of SiC fibers

  Fundamentals modeling of solidification process
- LaRC: One university grant on polymer processing
- No program focused on modeling the process to enable advanced materials

STATE-OF-THE-ART

- Multi-disciplinary program in the early stages of development--advanced computers are enabling
- Mainly university activities, but no systematic program that satisfies NASA needs in understanding the process dynamics of polymers and high temperature materials
- Phase diagram of simple alloys predictable

MATERIAL SCIENCE

COMPUTATIONAL MATERIALS

OAET — MATERIALS & STRUCTURES

TECHNOLOGY NEEDS

- Strongly recognized by NRC report as a "breakthrough" area
- Accelerated development of processes to produce advanced materials -- emphasis on ceramics and polymers for high temperature structures
- Process models for advanced composites
  - Polymer cure and crosslink process models
  - Models for polymer composite fiber-matrix processing interaction
  - Solidification models (nucleation and growth) in a realistic reactor environment
- Validated models for various processes
  - High temperature consolidation
  - Continuous flow laser float zone
  - Plasma-based processes
- Specially designed analysis validation experiments

THRUST(S) SUPPORTED

- Space Science
- Transportation

OBJECTIVE:

Develop computational methods to predict chemical kinetics and material properties from first principles

- Properties of metals
- Solid-gas reactions
- Properties of polymers
- Surface chemistry

PAYOFF

Processing optimized to produce structural materials with desired properties

Processes with near optimal yield

Reduced experimental costs

PRODUCTS (FY 1993 - FY 1996)

FY95: Accurate predictions of structural properties of polyimide polymer chains (e. g., stiffness, strength, CTE)

FYXX: Accurate models of hydrogen embrittlement in light alloys

MATERIALS & STRUCTURES

(R&T Base FY 1993 Augmentation)

MATERIAL SCIENCE

COMPUTATIONAL CHEMISTRY

RATIONALE

Material properties are controlled by complex interaction of many parameters

Experimental methods cannot economically determine sensitivity of material properties to the interaction of the process parameters

Advanced *ab initio* computational methods can accurately predict material properties

(Complements Computational Materials)

CENTERS

ARC

AUGMENTATION	TOTAL ($K)
FY 1993	500
FY 1994	1000
FY 1995	1500
FY 1996	1500

CofF: None

MATERIAL SCIENCE
COMPUTATIONAL CHEMISTRY

OAET MATERIALS & STRUCTURES

CURRENT PROGRAM

- Ames Research Center:
  - Properties of polymers and metal clusters
  - Gas-metal interaction studies
    - Chemsorption of O2 on nickel
    - Dissociation of O2 and H2 by nickel

STATE-OF-THE-ART

- Properties of metal clusters of up to 20 atoms
- Interactions of inner electron shells can only be approximated
- Accurate stiffness of simple polymers
- Capability applied to H2-O2 combustion kinetics
- Capability applied to hot gas aerobrake/entry studies

COMPUTATIONAL CHEMISTRY

TECHNOLOGY NEEDS

- **Incorporation of molecular dynamics to model diffusion**
- **Analysis methods to efficiently transition from groups of molecules to bulk material**
- **Polymer dynamics and crosslinking models**
- **Capability to model material singularities (e. g., grain boundaries)**
- **Accurate prediction of properties of bulk materials**

THRUST(S) SUPPORTED

- Transportation
- Space Exploration

OBJECTIVE:

Develop refractory metals and refractory metal composites for space nuclear propulsion and power

Develop advanced graphite copper composites for space power thermal management

PAYOFF

Higher thermal efficiency, decreased system weight, extended component life, and increased system reliability and safety

PRODUCTS (FY 1993 - FY 1996)

- Refractory metal composite fuel cladding with extended temperature and life capabilit
- Advanced refractory metal alloys with higher temperature capabilities
- High efficiency, low mass graphite copper composite thermal management systems

MATERIALS & STRUCTURES

(R&T Base FY 1993 Augmentation)

MATERIAL SCIENCE

POWER & PROPULSION MATERIALS

RATIONALE

Space nuclear propulsion and advanced nuclear power systems will require advanc ed materials capable of sustained operations at temperatures between 2500F and 5000F

Metal Matrix composites provide unique combinations of excellent thermal thermal conductivity and high modulus for Thermal Management Systems

CENTERS

LeRC

AUGMENTATION	TOTAL ($K)
FY 1993	500
FY 1994	900
FY 1995	1250
FY 1996	1600
FY 1997	2000

CofF: None

MATERIAL SCIENCE

POWER AND PROPULSION MATERIALS

OAET — MATERIALS & STRUCTURES

CURRENT PROGRAM

- $712K at LeRC to evaluate high temperature monolithic and composite ceramics and metals

STATE-OF-THE-ART

- Large Creep Property Database Developed for Niobium Alloys (Nb-1Zr and PWC-11)
- Total Niobium Alloy Creep Testing > 500,000 Hours (Longest Test 35,000 Hours at 2000F)
- Preliminary Testing of Soviet Monocrystal Molybdenum at 3000F
- Tungsten Fiber Reinforced Niobium Creep Strength 10X PWC-11
- Graphite Copper Composite/Titanium Heat Pipe Tested

MATERIAL SCIENCE

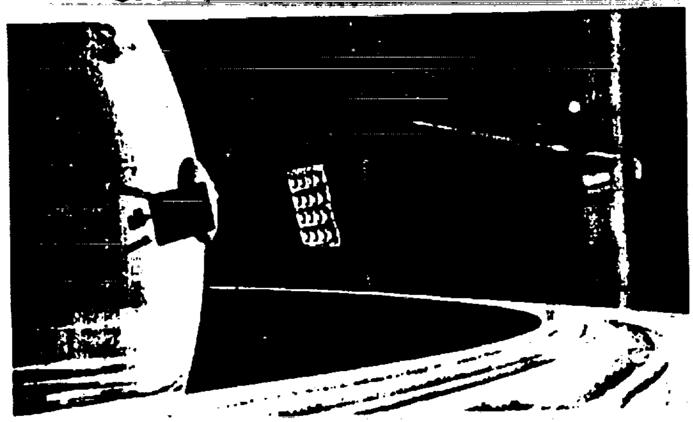
POWER AND PROPULSION MATERIALS

OAET — MATERIALS & STRUCTURES

TECHNOLOGY NEEDS

- High Temperature, Creep Resistant Materials for Nuclear Power Systems
- Very High Temperature, High Strength Materials for Nuclear Propulsion Systems
- Advanced, High Temperature Composite Systems for Nuclear Power Applications
- Low Mass, High Conductivity Materials for Thermal Management Systems

SPACE POWER MATERIALS

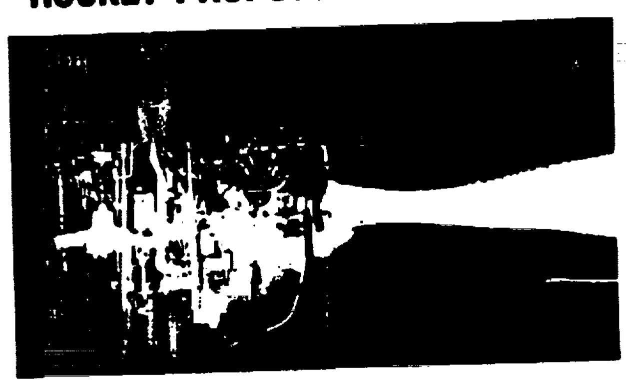


- REFRACTORY METALS (Nb-1Zr, PWC-11)
- W WIRE REINFORCED Nb-1Zr COMPOSITES
- ADVANCED WIRES (W-BASE, Mo-BASE)
- Gr/Cu COMPOSITES

CD-89-43457

ATD AEROSPACE TECHNOLOGY DIRECTORATE
MATERIALS DIVISION
ADVANCED METALLICS BRANCH
NASA Lewis Research Center

ROCKET PROPULSION MATERIALS

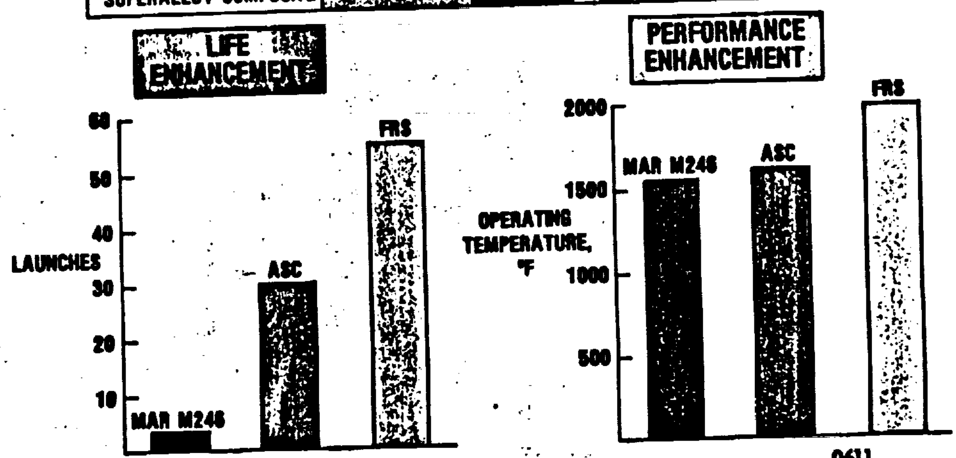


- HYDROGEN EFFECTS ON SINGLE CRYSTALS
- W/SUPERALLOY COMPOSITES
- W/Cu COMPOSITES
- RAPIDLY SOLIDIFIED Cu ALLOYS
- XD Cu ALLOYS

CD-89-43459

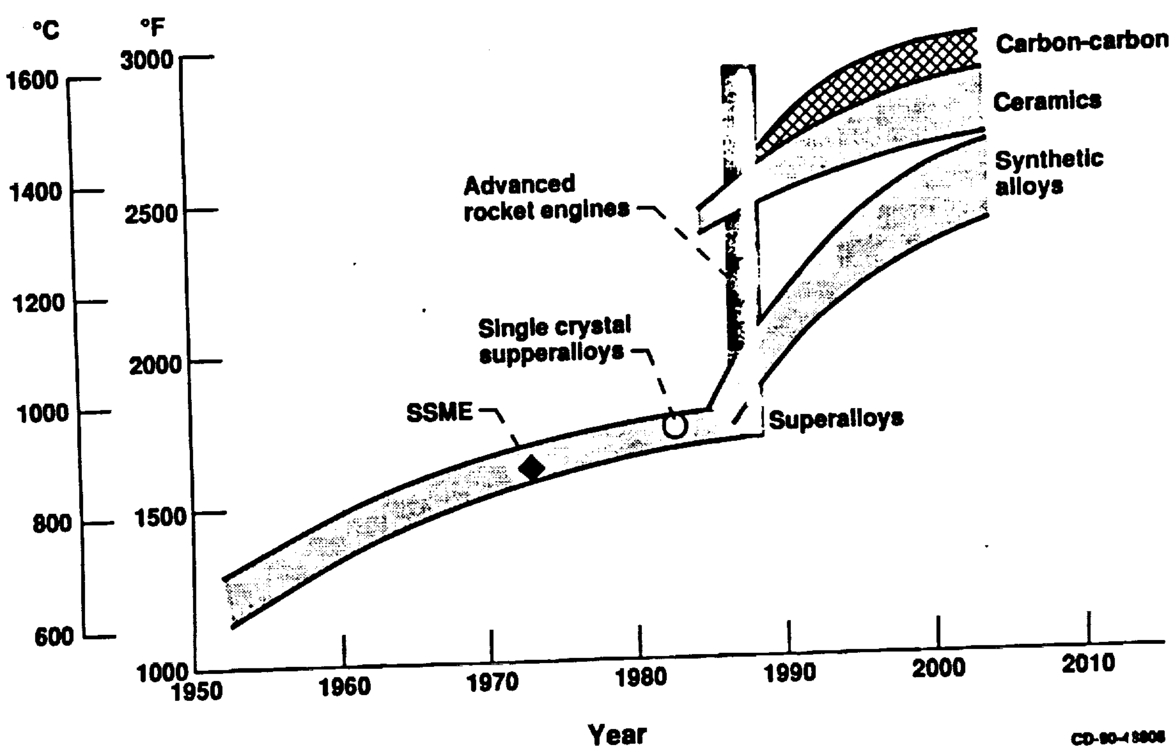
BETTER MATERIALS FOR ROCKET ENGINE TURBINE BLADES

MATERIALS	BENEFITS		AVAILABLE	
	PERFORMANCE	LIFE	NEAR TERM	LONG TERM
ADVANCED SINGLE CRYSTAL SUPERALLOY				
FIBER REINFORCED SUPERALLOY COMPOSITE				



0611
CD-84-14810

ROCKET ENGINE TURBOPUMP MATERIAL TRENDS



THRUST(S) SUPPORTED

- Space Station Freedom
- Science

PROGRAM CONTENT

- Combined Environmental Effects
- LDEF Data Analysis
- Contamination of Spacecraft
- Long-life Simulation & Cert.
- Space Durable Materials

CENTERS: LaRC, LeRC; JPL, (JSC, GSFC)

RESOURCE INFORMATION

FUNDING	NET ($K)
FY-90	2720
FY-91	2220
FY-92	1330

MANPOWER A(FY-91 EST.) = 23

MAJOR FACILITIES: None

MATERIALS & STRUCTURES
(R&T Base)

ENVIRONMENTAL EFFECTS & DURABLE MATERIALS

19.6 % of R&T Base
$11,350K (FY91)

PAYOFF

- Models and Test Methods to Assess Material Behavior and Durability
- Long-Life Structural Materials
  - Composites
  - Adhesives
  - Protective & Thermal Coatings

DELIVERABLES

- LDEF Analysis
  - Refined Meteroid/Debris Environ - 1991
  - Evaluation of Long-Term Durability of Silver-Teflon - 1991
- Space-Curable Composite for Deployable Structures - 1993

MAJOR CHANGES 90-91

Space Environmental Effects Program Focused on LDEF Analysis

MAJOR CHANGES 91-92

None Planned

SPACE ENVIRONMENTAL EFFECTS

OAET

MAJOR ISSUES

- ROLE OF MATERIALS IN SYSTEMS FAILURES
- UNKNOWNS OF COMPLEX NATURAL ENVIRONMENT
- LIMITATIONS OF GROUND-BASED SIMULATION
- USE OF "OFF-THE-SHELF" MATERIALS
- ENGINEERING BASIS FOR CERTIFICATION

SPACE ENVIRONMENTAL EFFECTS

OAET

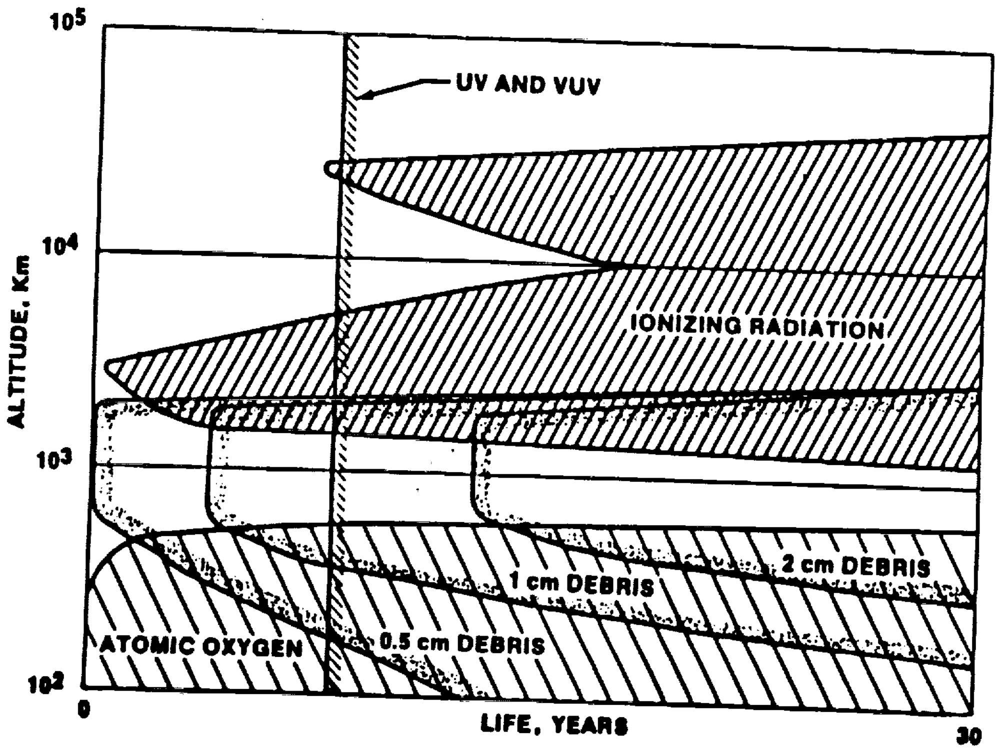
CONCERNS

- LARGER SPACECRAFT
- VULNERABLE LIGHTWEIGHT MATERIALS
- MINIMUM GAGE STRUCTURES
- LARGER ONBOARD POWER SOURCES
- LONGER FLIGHT DURATIONS
- HAZARDOUS ORBITS

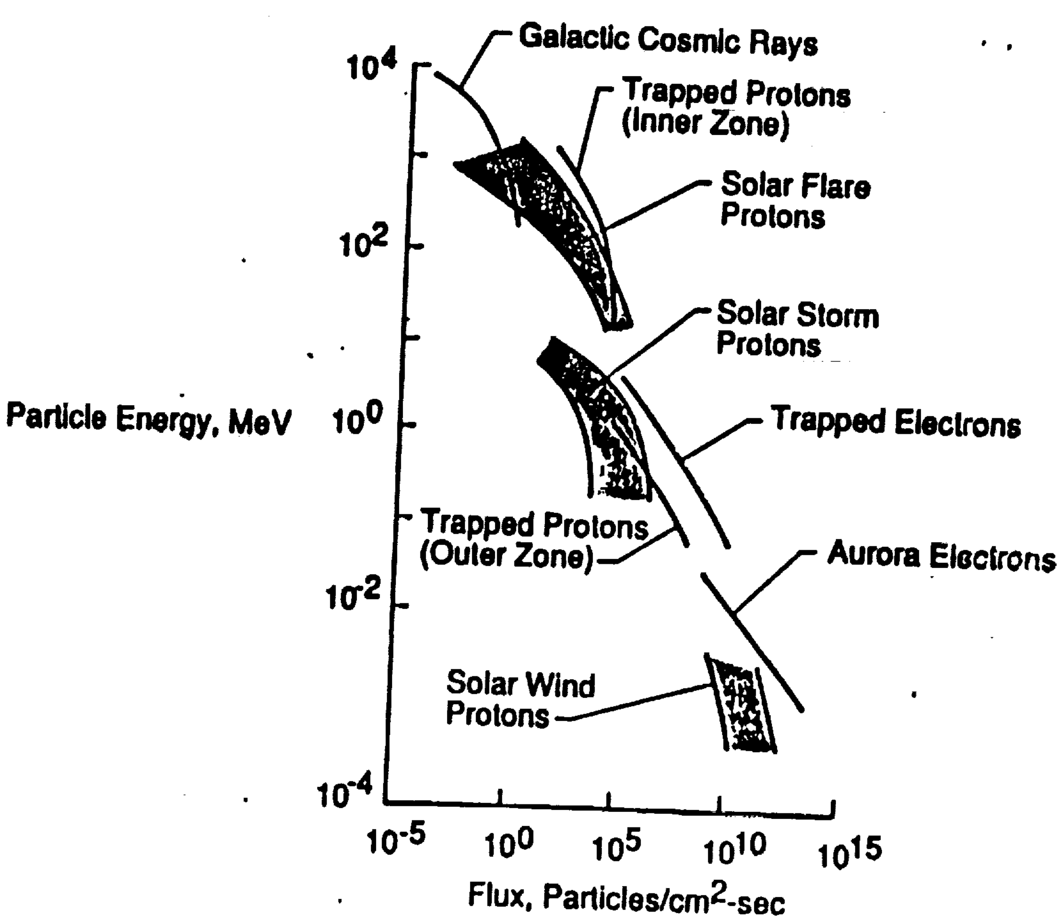
SPACE ENVIRONMENTAL PARAMETERS

Environmental parameter	Nominal range of parameter	Reasons for interest in parameter
Vacuum	Pressure 10^{-5}-10^{-13} mPa	Vacuum outgassing results in loss of moisture and solvents resulting in dimensional changes
Ultraviolet	Wavelength 0.1-0.4um intensity 1.4 Kw/m ^{2}	Degradation of coatings
Protons	Energy 0.1-4 MeV Flux 10^8 P^+/cm^2-sec	Degradation of coatings and surface plies of composites
Electrons	Energy 0.1-4 MeV Flux 10^8 e^-/cm^2-sec	Surface and bulk damage; spacecraft charging
Temperature cycling	Material temp. 80 K to 420 K	Microcracking, thermal warping, deterioration of antenna gain due to surface distortions

IM. ACT OF ENVIRONMENTAL FACTORS ON SYSTEMS



SPACE RADIATION ENVIRONMENT



THRUST(S) SUPPORTED

- Space Platforms
- Space Science
- Operations

OBJECTIVE:

Develop techniques to protect space systems from meteoroid and debris damage

- Hypervelocity impact analysis
- Test methods
- Lightweight shielding
- Impact damage detection

RATIONALE

Orbital debris is currently a possible threat in LEO

Orbital debris has become an international issue due to concern over damage

Orbital debris has become an international issue due to possible danger

Current shielding methods can impose heavy weight penalties on spacecraft

Impact/shielding properties of advanced materials not well known

MATERIALS & STRUCTURES

(R&T Base FY 1993 Augmentation)

SPACE ENVIRONMENTAL EFFECTS

ORBITAL DEBRIS

PAYOFF

Improved safety, especially in LEO

Lower spacecraft weight

Reduced orbital debris generation

PRODUCTS (FY 1993 - FY 1996)

FYXX: Enhanced ground test capability--1 Gm Al at 11km/sec versus 7 km/sec today

FY94: Multi-layer shield concept 70% lighter than current aluminum Whipple shield

FYXX: Penetration detection technique

FYXX: Accurate impact/shielding analysis of composite materials

CENTERS

JCS, MSFC, (LaRC)

RESOURCES

AUGMENTATION	TOTAL ($K)
FY 1993	500
FY 1994	800
FY 1995	900
FY 1996	1000
FY 1997	1200

CofF: None

SPACE ENVIRONMENTAL EFFECTS
ORBITAL DEBRIS

OAET — MATERIALS & STRUCTURES

CURRENT PROGRAM

- $50K (net) at JSC to support testing and analysis
- IN-STEP Phase B on the Debris Collision Warning Sensor
- Extensive Space Station Freedom design studies to provide protection from debris and micrometeorites using current technology

STATE-OF-THE-ART

- Hydrocode ("fluid analogy") analysis of hypervelocity impact
- Weight inefficient aluminum Whipple bumper still standard
- Limited database on nonhomogeneous materials (composites, woven ceramics, metal meah, carbon felt, etc.)
- 200% to 300% uncertainty in debris population in the critical .1 cm to 2 cm size range - greatest threat in LEO
- Several concepts proposed that are likely to provide major improvements in safety and weight

ORBITAL DEBRIS

TECHNOLOGY NEEDS

- Safe lightweight debris protection systems
- Database on advanced shielding materials
- Realistic test methods
  - Size up to 2 cm
  - Speed up to 15 km/sec (probably requires additional facility investment)
  - Nonspherical shape
  - Projectile density ranging from ice (1 gm/cc) to steel/copper/silver/ (8 gm/cc)
- Accurate analytical models based on physics and mechanics--not just empirical data and phenomenological models
- Analytical capability to assess spacecraft damage and survivability
- Improved debris population growth and evolution models
- Impact damage detection techniques

THRUST(S) SUPPORTED

- Exploration
- Transportation

PROGRAM CONTENT

- Advanced Ablative Heat Shield Concepts
- Adv. Lightweight Reusable Insulative TPS
- Thermal Structural Concepts
- Computational Methods to Predict Structural Behavior
- Validation testing

PAYOFF

- 25% Lighter Structures
- 50% Lighter Ablative TPS
- Toughened Lightweight TPS
- Higher Use Temp. (Reusable > 3000 F)

DELIVERABLES

- 1600 F Curved Metallic TPS - 1991
- Toughened (x100) TPS Coating - 1991
- 1800 F Flexible Ceramic TPS - 1992
- Lightweight C-C Heatshield Material - 1992
- Transient High Temperature Structural Analysis Code for Adv. Vehicles - 1992

MATERIALS & STRUCTURES
(R&T Base)
AEROTHERMAL MATERIALS AND STRUCTURES
27.4 % of R&T Base
$11,350K (FY91)

CENTERS: LaRC, ARC

RESOURCE INFORMATION

FUNDING	NET ($K)
FY-90	2840
FY-91	3110
FY-92	3110

MANPOWER (FY-91 EST.) = 47

MAJOR FACILITIES: Arc Jet (ARC), 8'-High Temp. Tunnel (LaRC)

MAJOR CHANGES 90-91

Increased Emphasis on High Energy TPS (e.g. Planetary/Earth Entry, Ablators)

MAJOR CHANGES 91-92

(Need to Upgrade Arc Jet Capacity to 300MW - FY96 CofF)

THRUST(S) SUPPORTED

- Transportation
- Space Science (e. g. Solar Probe)

OBJECTIVE:

Develop materials and concepts for durable high temperature thermal protection systems for advanced space transportation and planetary entry systems, including:

- Ceramic
- Metallic
- Ablative

PAYOFF

- 500°F to 1000°F increase in TPS capability
- 10X TO 100X increase in durability
- 30% to 50% lighter ablative TPS
- Reduced maintenance cost

PRODUCTS (FY 1993 - FY 1996)

- *4000 °F rigid TPS material - FY 1994*
- *Toughened (X100) rigid ceramic TPS - FY 1994*
- >2500°F flexible TPS system
- 30% lighter ablator for probes and aerobrakes
- Concept for >3000°F durable leading edge
- *Low mass loss ablaative TPS - FY 1996*

MATERIALS & STRUCTURES

(R&T Base FY 1993 Augmentation)

AEROTHERMAL MATERIALS & STRUCTURES

THERMAL PROTECTION SYSTEMS

RATIONALE

Current rigid and flexible TPS is based on 10+ year old material concepts

Temperature is limited to <3000°F and rigid TPS systems (e. g., shuttle tiles) are easily damaged

State of the art in ablative TPS is from the Apollo era

TPS performance is a mission limiting factor in spacecraft and entry vehicle design

CENTERS

ARC, (JPL, LARC)

AUGMENTATION	TOTAL ($K)
FY 1993	800
FY 1994	1100
FY 1995	1400
FY 1996	1700
FY 1997	2000

CofF: FY 1996–300-MW Arcjet at ARC

AEROTHERMAL MATERIALS AND STRUCTURES
THERMAL PROTECTION SYSTEMS

OAET MATERIALS & STRUCTURES

CURRENT PROGRAM

- Toughened coatings for rigid ceramic TPS
- Low density ceramic TPS for +3000°F use
- Polymer precursors for advanced ceramic TPS
- Large area flexible ceramic TPS
- Advanced analysis method to model ablation

STATE-OF-THE-ART

- 2500°F rigid ceramic TPS (space shuttle tiles)
- 1200°F flexible TPS (about 30% of current shuttle TPS)
- 35 lb/cu ft Apollo era polymeric ablator

TECHNOLOGY NEEDS

- Higher temperature capability: Transportation
  - Flexible ceramic TPS over 2500 °F
  - Rigid ceramic TPS over 3000 °F
- Lower mass loss
  - > 2.5 mg/sec for entire Solar Probe heat shield
- Lightweight ablators
  - Large aerobrakes for transfer vehicles
  - Science probes - e.g. MESUR (Mars Environmental Survey), Cassini Probe to Saturn
- Reusability
  - >10 times tougher ceramic TPS tiles
  - Multiple use ablators for high energy aerobrakes
- Convenient replacement
- Interchangeability
- Flexibility

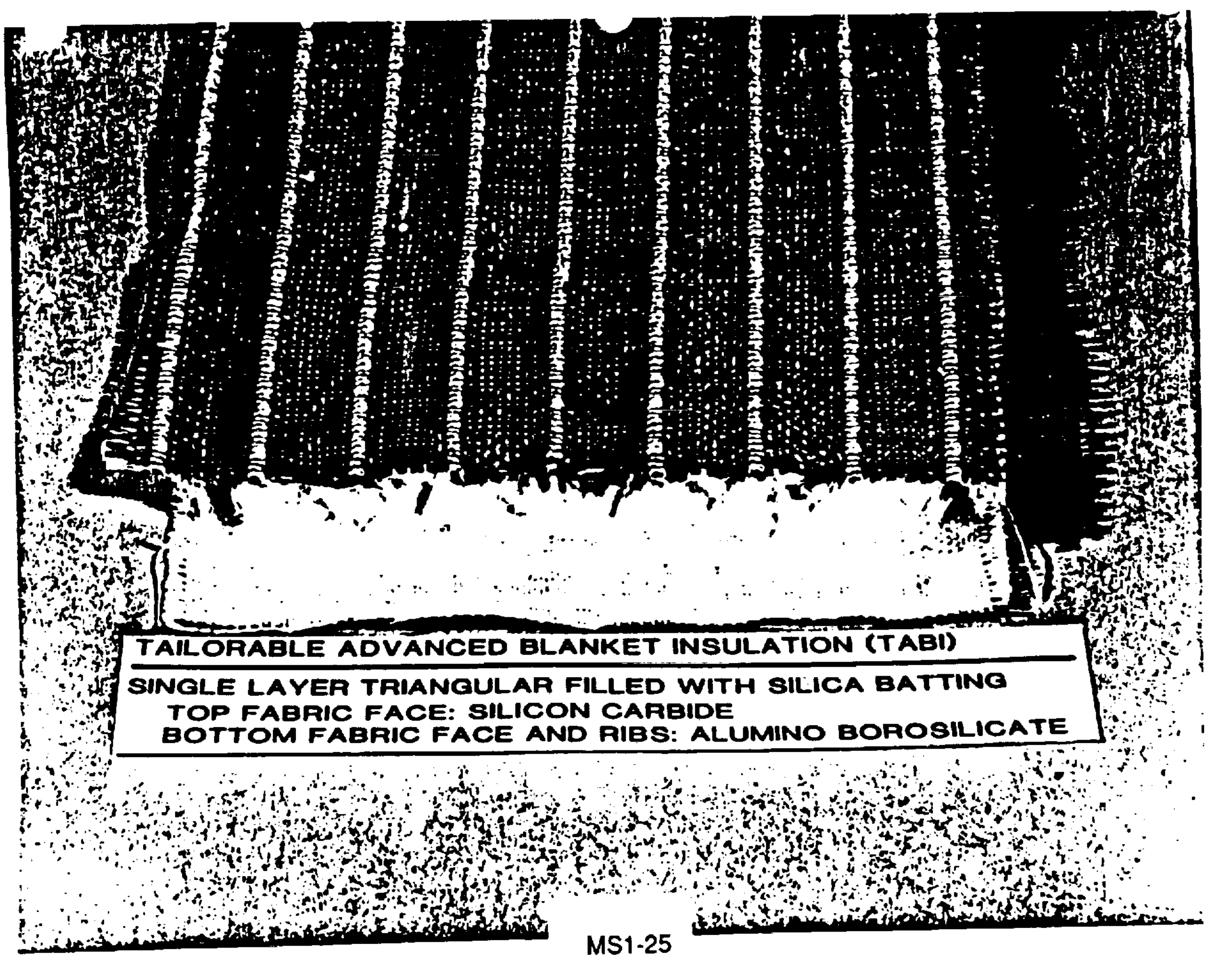
BACKGROUND
FLEXIBLE CERAMIC INSULATION

- FLEXIBLE, SEWN SILICA INSULATION BLANKETS CALLED "AFRSI" DEVELOPED IN 1970'S AS EXTERNAL TPS FOR SPACE SHUTTLE.
  - OVER 4000 FT^2 APPLIED TO SELECTED SURFACES OF ALL ORBITER VEHICLES.
  - MULTIPLE FLIGHT USE DEMONSTRATED FOR TEMPERATURES UP TO 1200°F
- INTEGRAL WOVEN CORE INSULATION STRUCTURES CALLED "TABI" DEVELOPED IN 1980's FOR APPLICATION TO ADVANED SPACE VEHICLES.
  - DESIGNATED AS PART OF ALTERNATE TPS EXPERIMENT FOR AFE.
  - IDENTIFIED AS TPS CANDIDATE FOR AFE CARRIER VEHICLE.
  - HIGHER TEMPERATURE CAPABILITY THAN AFRSI (1800+°F).
  - LONGER AEROACOUSTIC SURVIVAL TIME THAN AFRSI.
- CURRENTLY TECHNOLOGY BEING CONSIDERED FOR CERV, MMRV, MSRV, HERMES, AND OTHER DOD VEHICLES.

CERAMIC THERMAL . ROTECTION SYSTEM TECHNOLOGY PROJECTIONS

MATERIAL TEMPERATURE CAPABILITY, °F FOR MULTIPLE REUSE

MATERIAL	1982	1990 TECHNOLOGY GOAL
RIGID REUSABLE SURFACE INSULATION LI-2200, FRCI, HTP, AETB	2700	3000
FLEXIBLE SURFACE INSULATION AFRSI, TABI	1200-1800	1800-2500
HIGH DENSITY CERAMIC COMPOSITES RCC, ACC, SIC/SIC	2800-3200	3800-4000

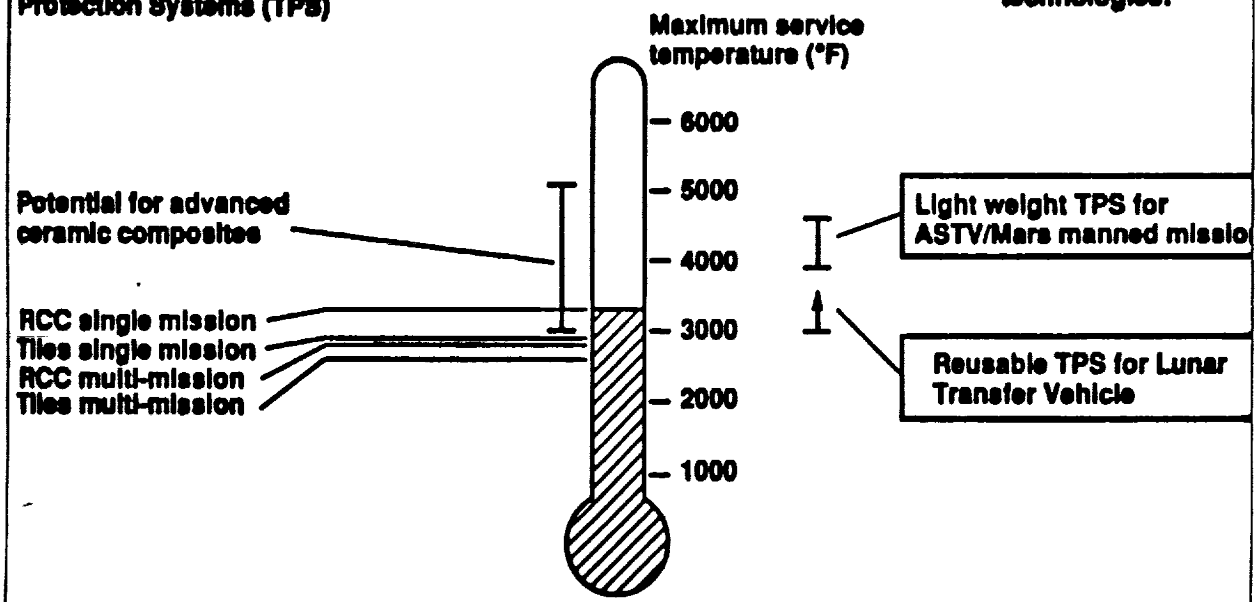


TAILORABLE ADVANCED BLANKET INSULATION (TABI)

SINGLE LAYER TRIANGULAR FILLED WITH SILICA BATTING
TOP FABRIC FACE: SILICON CARBIDE
BOTTOM FABRIC FACE AND RIBS: ALUMINO BOROSILICATE

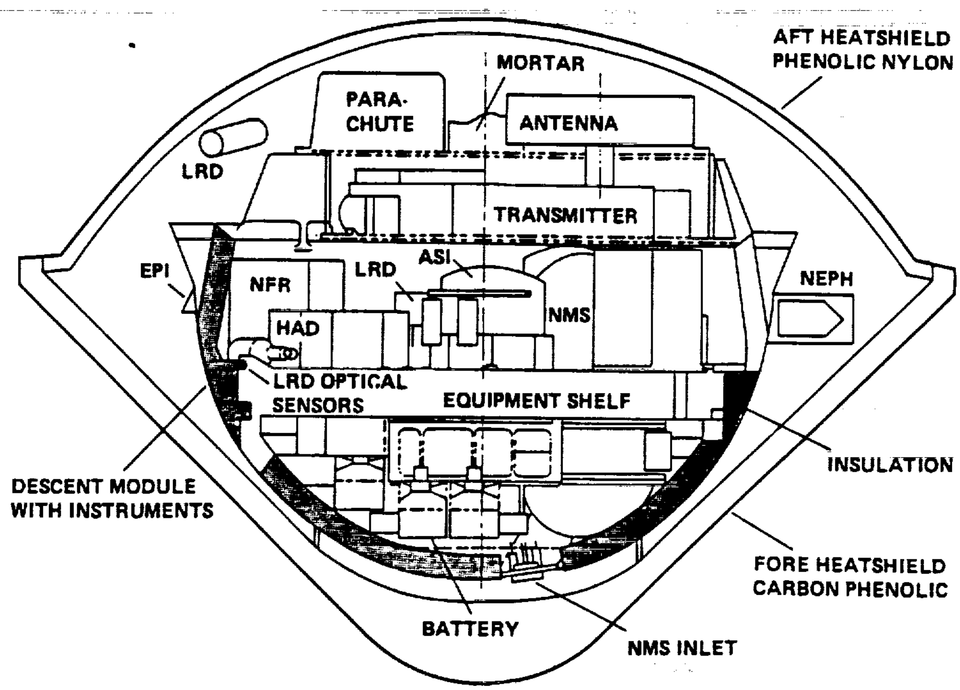
Reusable Thermal Protection Systems (TPS)

OAST identified criti technologies:

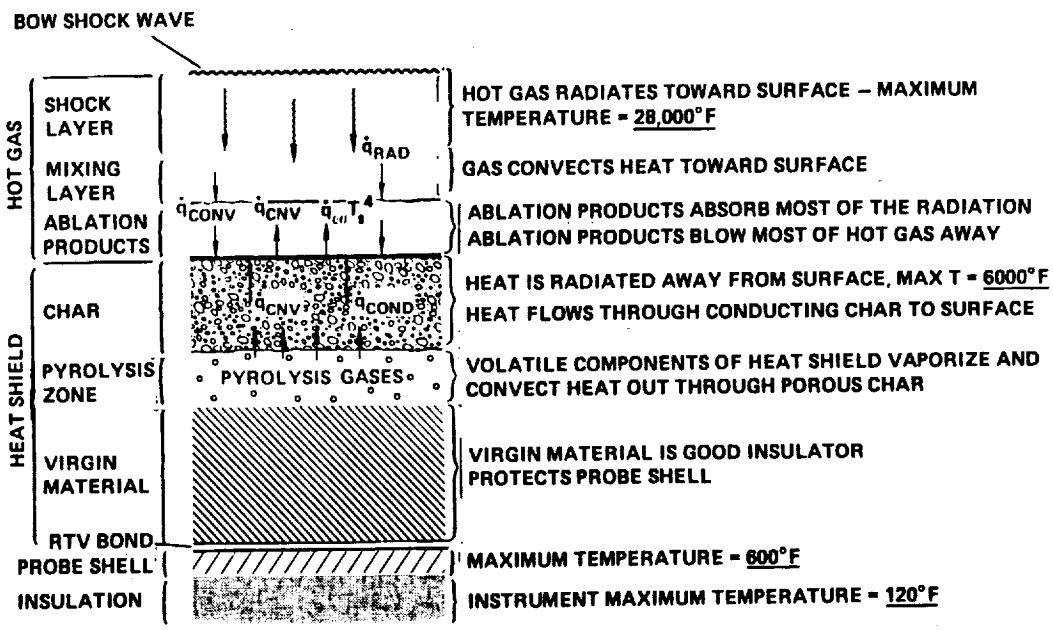


- **Development of higher temperature TPS materials is a NASA critical technolo**

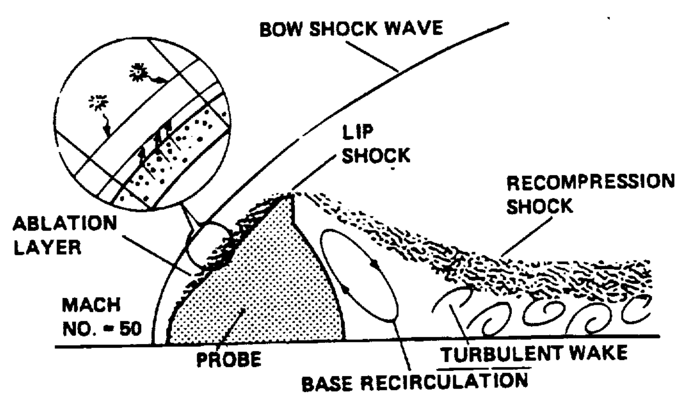
GALILEO PROBE BEFORE ENTRY



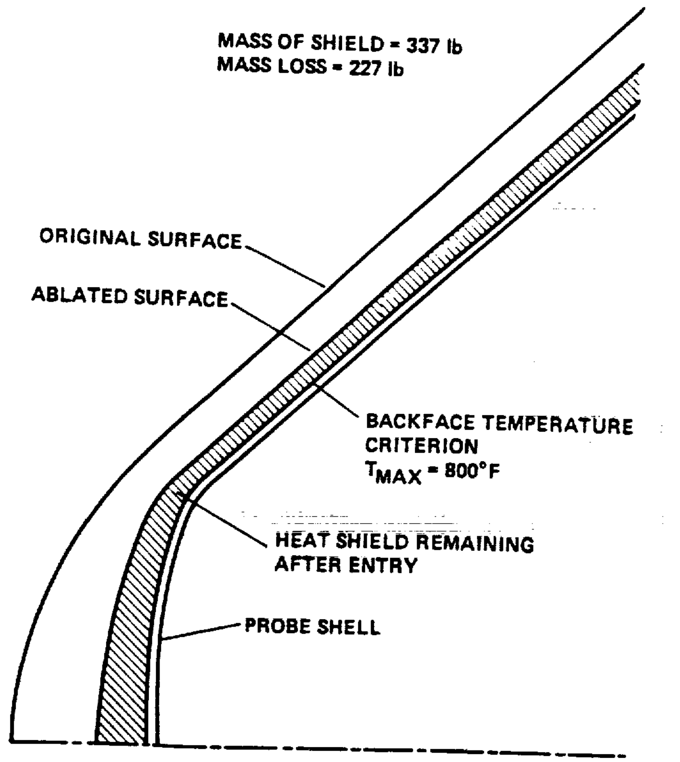
MECHANISMS FOR PROBE THERMAL PROTECTION



HOT GAS FLOW AROUND PROBE DURING AERODYNAMIC BRAKING



HEATSHIELD SHAPE BEFORE AND AFTER ENTRY ABLATION



MATERIALS & STRUCTURES

(R&T Base FY 1993 Augmentation)

AEROTHERMAL MATERIALS & STRUCTURES

ARCJET RESEARCH

THRUST(S) SUPPORTED

- Transportation
- Operations

OBJECTIVE:

Provide significant improvement in the ground-based simulation of hypervelocity flight.

RATIONALE

Arc jets have played an enabling role in the development of hypervelocity vehicles from early in the NASA space program to the present.

Future programs require arc jets of ever increasing capabilities.

The existing facilities are 20 years old (or more) and are increasingly costly to maintain and operate.

PAYOFF

Leadership in arc jet test capability

National arc jet research capability

PRODUCTS (FY 1993 - FY 1996)

FY93: Advanced arc heater concept tests

FYXX: Scaling laws developed

FYXX : Pilot arc heater operational

CENTERS

ARC

AUGMENTATION	TOTAL ($K)
FY 1993	500
FY 1994	600
FY 1995	650
FY 1996	700
FY 1997	800

CofF: None

AEROTHERMAL MATERIALS AND STRUCTURES
ARCJET RESEARCH

OAET — MATERIALS & STRUCTURES

CURRENT PROGRAM

- Development of high enthalpy, low pressure arc-heaters for atmospheric entry simulation of manned space vehicles, particularly the Space Shuttle
- Japan - large study underway for the design and development of a 60MW facility
- ESA - developing a 70MW arc-heated wind tunnel facility

STATE-OF-THE-ART

- Six arc-jet facilities ranging from 20 to 120 MW input power
- Smaller facilities exist in China, France, Germany, Israel, and the USSR

AEROTHERMAL MATERIALS AND STRUCTURES
ARCJET RESEARCH

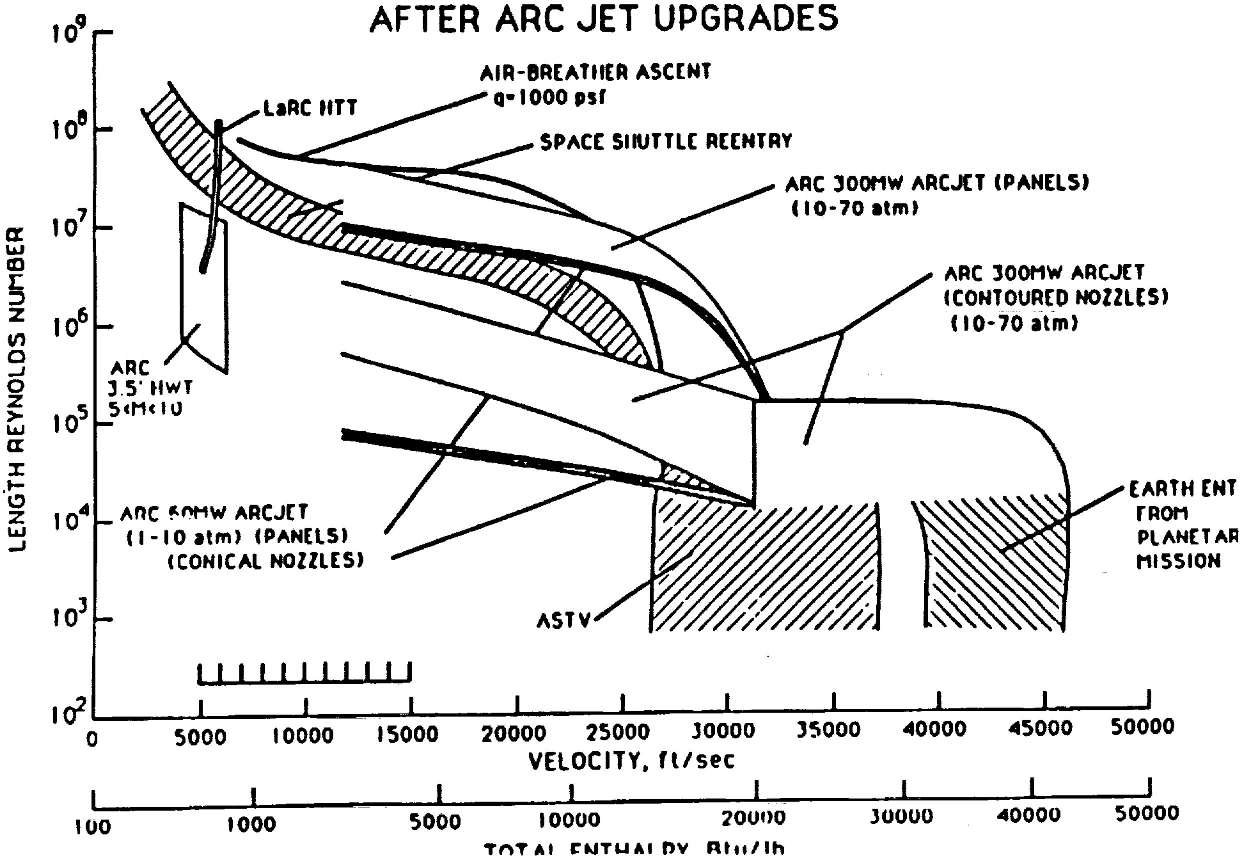
OAET — MATERIALS & STRUCTURES

TECHNOLOGY NEEDS

- Strong technological base to support future arc jet development
- High enthalpy (40,000 Btu/lb) and high pressure (200 atm) capability
- Improved instrumentation and diagnostics

FACILITY SIMULATION OF HYPERSONIC FLIGHT

AFTER ARC JET UPGRADES



THRUST(S) SUPPORTED

- SCIENCE
- TRANSPORTATION

OBJECTIVE:

Develop a lightweight heat shield concept for a Solar Probe science mission

- Materials and coatings
- Structural concept
- Fabrication methodology

RATIONALE

Large lightweight concept requires structural TPS shield - beyond current state of the art

Stringent requirements for low mass loss at high temperature are not currently possible without heavy refractory metals

Advanced ceramics (e.g. carbon-carbon) offer high probability of success but are at a low level of technology readiness

TRANSPORTATION/BASE R&T

SPACE VEHICLE STRUCTURES &

AEROTHERMAL MATERIALS AND STRUCTURES

SOLAR PROBE

SCHEDULE

Base R&T FY1993 - FY 1995

Validated material system

Preliminary structural shield concepts

Focused Program FY 1995 - FY 1998

Validated structural concept

Validated shield fabrication methods

Validated support/load transfer structure concept

Validated "cold side" thermal performance

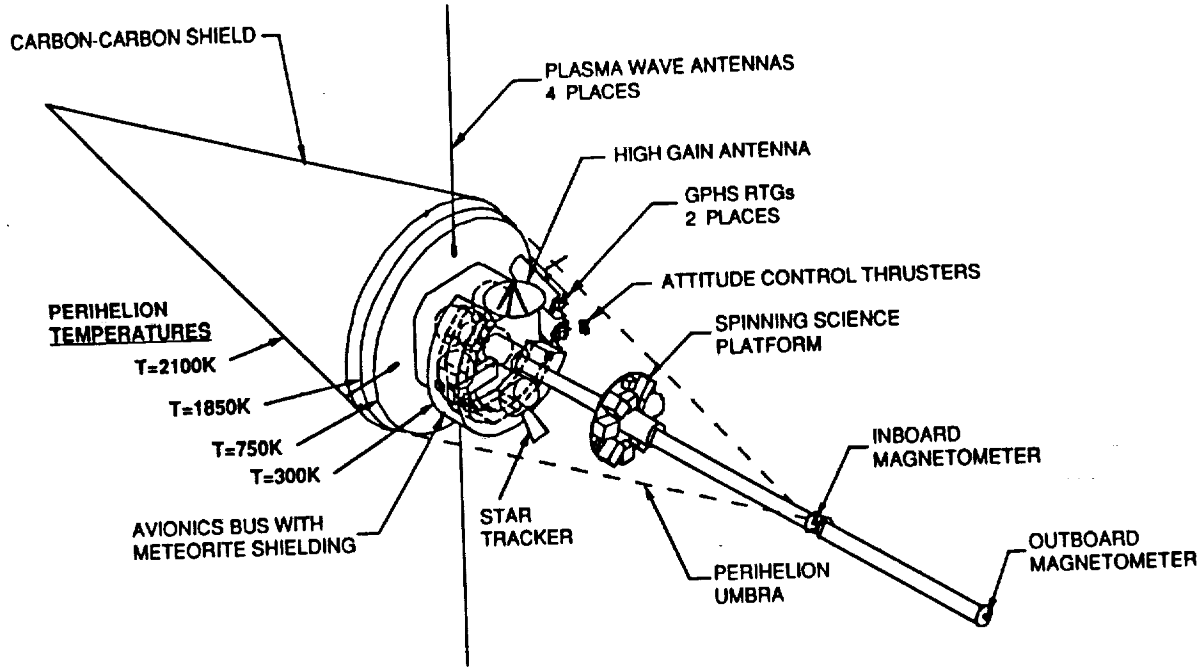
CENTERS

JPL, ARC (LaRC)

AUGMENTATION	TOTAL ($K)
FY 1993 - FY 1995	500 - 1000
FY 1995 - FY 1998	3000 - 5000

(Total costs not coverd in current or proposed "x3" budget)

CofF: None



SOLAR PROBE

OAET — MATERIALS & STRUCTURES

- Solar Physics mission to study the solar corona
  - Coronal structure
  - Coronal heating
  - Solar wind acceleration
  - Plasma turbulence within the solar envelope
  - Acceleration and transport of energetic particles
  - Solar dust environment

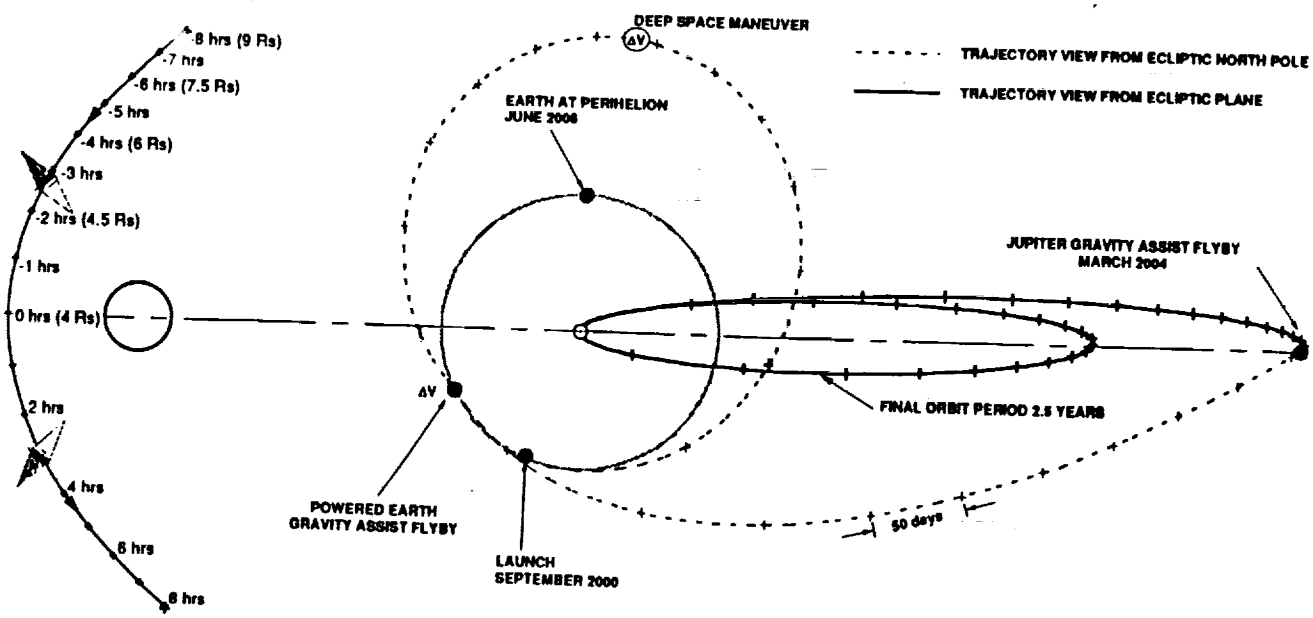
- Closest approach to the sun: 4 solar radii

- New start about the end of the decade

- Very demanding weight and material requirements

a. Perihelion Trajectory

b. Interplanetary Trajectory



SOLAR PROBE

OAET — MATERIALS & STRUCTURES

CURRENT PROGRAM

- **Detailed system studies by the Space Physics Division of the Office of Space Science and Applications**
  - **Mission scenario: Launch requirements, trajectory, etc.**
  - **Thermal load analysis**
  - **Shield requirements**
  - **Evaluation of state-of-the-art materials**
- **Carbon-carbon technology being developed for hypersonic vehicles**

STATE-OF-THE-ART

- **Heavy refractory metals**
- **Carbon-carbon with absorbtance/emittance approx. 1.0**
- **Polymer-based ablator**
- **Current data base and analysis of physical requirements indicate that a shield is possible**
- **Industry can fabricate thin carbon-carbon sheets in sized up to 2m x 4m**
- **Advanced highly reflective materials show promise for reducing thermal load**

SOLAR PROBE

OAET — MATERIALS & STRUCTURES

TECHNOLOGY NEEDS

- Total heat shield mass loss rate <2.5 mg/sec at 3500 °F - 4000 °F
- Weight below 500 Kg
- Stable properties for a 9 year mission
  - 3000 suns for about 4 hours during solar orbit (twice in 2.5 years)
  - Jupiter flyby environment (gravity assist into highly elliptical solar orbit)
  - Maximum temperature about 4000 °F during closest approach to the sun (4 solar radii)
  - Minimum temperature about - 280 °F during deep space transit
- Detailed material data base
  - Carbon-carbon first choice
  - Thin refractory (e.g. tungsten) as an option (with severe mass penalty)
  - Advnced high reflectivity coatings
  - Integrated solar absorbtance

Temperature range:	300 - 2600 Kelvin
Angle of incidence:	0° - 88° of surface normal
Spectral range:	0.2μm - 12μm for solar absorbtance 0.5μm - 20μm for solar emittance

SOLAR PROBE

OAET — MATERIALS & STRUCTURES

TECHNOLOGY NEEDS (continued)

- Carbon-carbon outgassing/sublimation
  - Temperature range: 300 - 2000 Kelvin for outgassing; 1900 - 24000 Kelvin for sublimation
- Synergistic charged particle radiation effects on materials
  - Surface erosion
  - Discoloration
  - Mass loss
  - Chance in absorbtance and emittance
- Micrometeoroid resistance (up to 300 km/sec at solar perihelion)
- Validated structural integrity of shield concept

THRUST(S) SUPPORTED

- Transportation

OBJECTIVE:

Develop interdisciplinary, structural design methods-based sensitivity analyses to increase the design efficiency of space vehicles

Demonstrate interdisciplinar design method on selected space structure

RATIONALE

Conventional design methods perform design one variable at a time using significant computational resources

New sensitivity analysis methods have potential to increase efficiency, however the need exists to demonstrate these methods on realistic engineering design problem

PAYOFF

Improved space transportation vehicle designs with savings of 10-30% in weight over conventional design methods.

PRODUCTS (FY 1993 - FY 1996)

FY93: Derive mutual influence among the technological disciplines.

FY96: Initiate design of large scale transportation vehicle (e. g., lunar transfer vehicle).

MATERIALS & STRUCTURES

(R&T Base FY 1993 Augmentation)

AEROTHERMAL MATERIALS & STRUCTURES

INTEGRATED DESIGN

CENTERS

LaRC

AUGMENTATION	TOTAL ($K)
FY 1993	300
FY 1994	375
FY 1995	450
FY 1996	500
FY 1997	600

CofF: None

AEROTHERMAL MATERIALS AND STRUCTURES
INTEGRATED DESIGN

OAET — MATERIALS & STRUCTURES

CURRENT PROGRAM

- Structural sensitivity analysis and optimization method currently being developed to determine the impact of a change of one part of a system on the whole system

STATE-OF-THE-ART

- Parametric studies or sequential design -- tracing effects of changes one variable at a time
- Prohibitively costly and drawn-out approach for anything but very preliminary designs
- Optimization method "wrapped around" collection of analysis programs -- not integrated
- Small effort in aeronautics has demonstrated improvement of propulsion efficiency by 13% over conventional methods

AEROTHERMAL MATERIALS AND STRUCTURES
INTEGRATED DESIGN

OAET — MATERIALS & STRUCTURES

TECHNOLOGY NEEDS

- Understanding of the mutual influences of various disciplines (aerodynamic, thermal, structural, propulsion, control)
- Application to large, realistic, engineering design problem
- Verification of potential improvements over conventional approaches

MATERIALS & STRUCTURES
(R&T Base)
SPACE STRUCTURES AND DYNAMICS
10.5 % of R&T Base
$11,350 K (FY91)

THRUST(S) SUPPORTED

- Exploration (and Science
  - Earth Observation
  - Astrophysics)
- Space Station and Breakthrough

PROGRAM CONTENT

- Automated Construction Methods
- Deployable & Adaptive Concepts
- Spacecraft Design, Analysis & Modeling *

* Funded Mostly Through CSI

PAYOFF

- Significantly Reduce EVA
- Mass & Packaging Volume Reduced 50%
- 100%-500% Improvement in Predicted On-Orbit Structural Response

DELIVERABLES

- Demonstrate Automated Assembly of a Precision Planar Reflector - 1991
- Structural Concept for an Adaptive Deployable Structure - 1992-1993
- Dynamic Analysis & Verification Methods for Evolutionary Space Station - 1994 *

CENTERS: LaRC, (JPL)

RESOURCE INFORMATION

FUNDING	NET ($K)
FY-90	1430
FY-91	1540
FY-92	2110

MANPOWER (FY-91 EST.) = 37

MAJOR FACILITIES: None

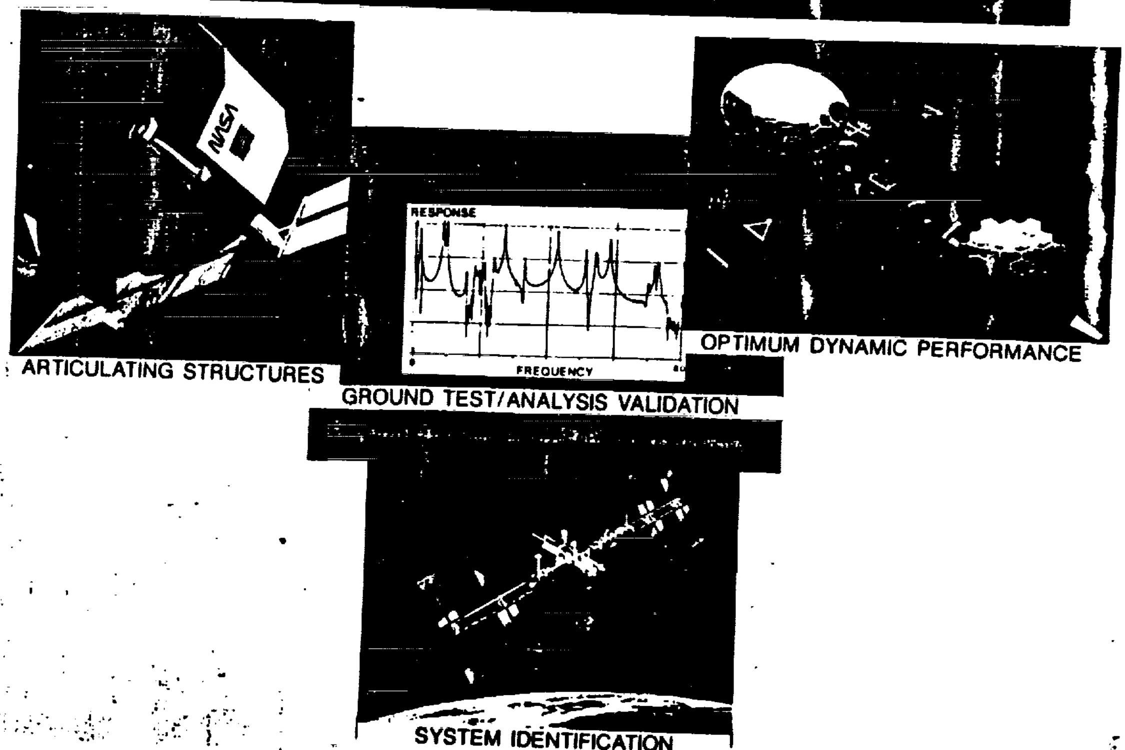
MAJOR CHANGES 90 - 91

- Expanded Space StructuresDynamics Laboratory to Support SSF (Dynamic Scale Model Test)*

MAJOR CHANGES 91-92

- Increased Emphasis on Automated Space Construction
- Proposed Initiation of Space Mechanisms Program

SPACECRAFT DYNAMICS RESEARCH



THRUST(S) SUPPORTED

- Space Platforms
- Operations (construction)
- Transportation (piloted vehicles)
- Exploration (habitats)

OBJECTIVE:

Develop advanced structural concepts for advanced platforms, large reflectors, precision structures, and critical structural components which permit the most cost effective means for orbital deployment and construction

Develop lightweight concepts for space habitats and piloted vehicles

PAYOFF

Lightweight, efficient space structures

Minimize orbital construction times and cost

Validated space construction methods

Safe, lightweight habitats for long duration space missions

PRODUCTS (FY 1993 - FY 1996)

Adaptive deployable planar truss concept

Methods for robotic assembly of a reflector system

Lightweight composite erectable joint

Design concept for lightweight nonmetallic spacecraft structures with integral thermal/radiation/debris protection

MATERIALS & STRUCTURES

(R&T Base FY 1993 Augmentation)

SPACE STRUCTURES

STRUCTURAL CONCEPTS AND SPACE CONSTRUCTION

RATIONALE

A limiting factor for many new missions is the ability to build large structures at a reasonable cost

Lack of experience with large space structures, limits mission studues to small spacecraft

New structural concepts are needed to reduce the weight of habitable modules for future space misions and meet environmental and safety requirements (e.g. radiation)

CENTERS

LaRC, JPL

AUGMENTATION	TOTAL ($K)
FY 1993	600
FY 1994	1300
FY 1995	1700
FY 1996	2200
FY1997	2600

CofF: None

SPACE STRUCTURES

STRUCTURAL CONCEPTS

OAET — MATERIALS & STRUCTURES

CURRENT PROGRAM

- Design, fabricate, and test a composite erectable joint
- Design, fabricate, and robotically install hexagonal panels on robotic truss
- Combine advanced concepts of optimization and sensitivity analyses with disciplinary analysis methods for efficient synthesis methodology applicable to large space structures and antennas.

STATE-OF-THE-ART

- Space station erectable 5-meter truss; composite tubes with aluminum nodes
- ACCESS established validity of erectability techniques, thermal protection wrap of struts; and, EVA timelines from Neutral Buoyancy Facility
- Fabrication technique for composite tubes with thin aluminum outer layer for thermal stability
- Space habitat modules based on Space Station Freedom designs
  - Aluminum structure
  - Non-integral environmental protection

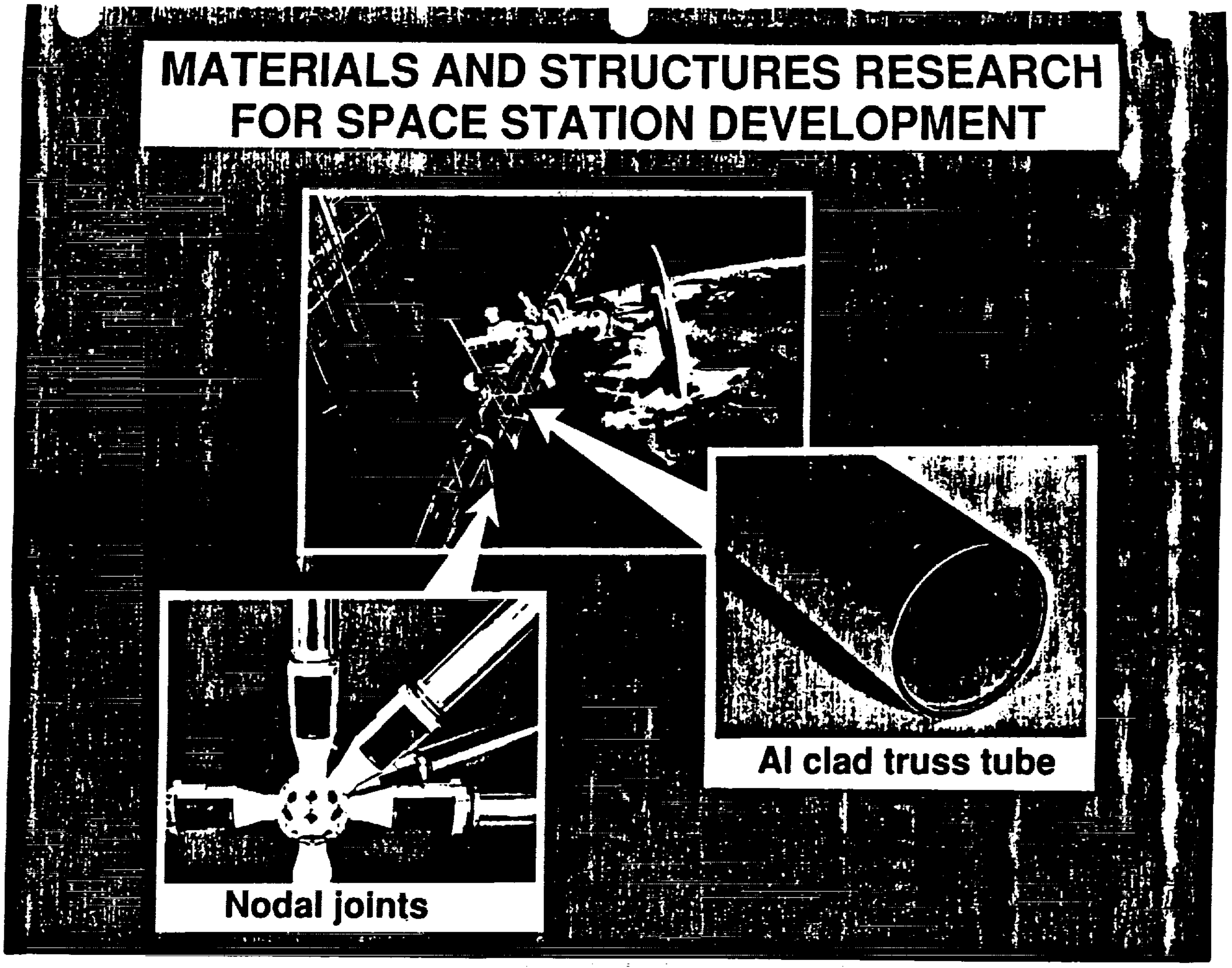
SPACE STRUCTURES

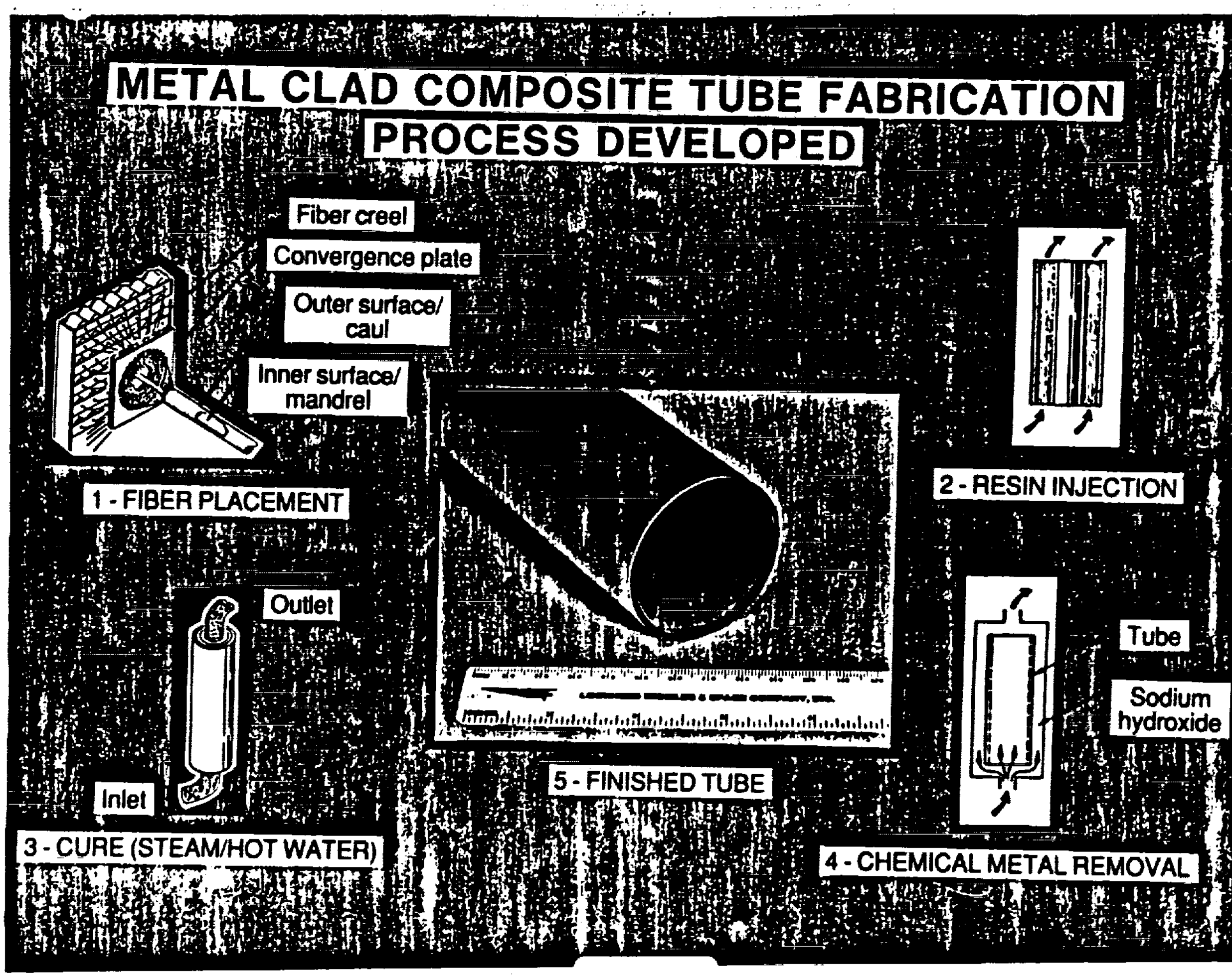
STRUCTURAL CONCEPTS

OAET — MATERIALS & STRUCTURES

TECHNOLOGY NEEDS

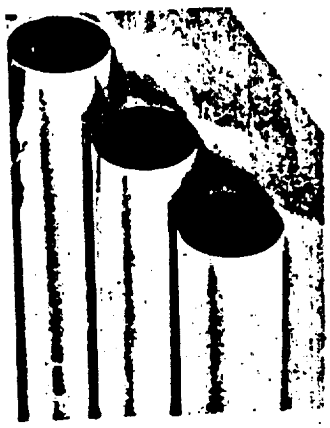
- Concepts for linear and area truss structures with integrated utilities
- Joints with quick-connect, pass-through utilities
- Advanced erectable concepts which facilitate minimum EVA time
- Efficient packaging for minimum launch volume
- Automated/telerobotic construction techniques and associated tools
- Lightweight, reliable deployable concepts for complex structures
- Design methods for optimal hybrid erectable and deployable structures
  - Accurate measure of construction time and resources (robots and astronauts)
  - Accurate design methods for deployable structures and dynamics
- Spaceraft wall and interior structure integrally optimized for lightweight and environmental protection (radiation, thermal, etc.)


MATERIALS AND STRUCTURES RESEARCH
FOR SPACE STATION DEVELOPMENT
Al clad truss tube
Nodal joints


METAL CLAD COMPOSITE TUBE FABRICATION
PROCESS DEVELOPED
Fiber creel
Convergence plate
Outer surface/ caul
Inner surface/ mandrel
1 - FIBER PLACEMENT
2 - RESIN INJECTION
Outlet
Inlet
3 - CURE (STEAM/HOT WATER)
5 - FINISHED TUBE
Tube
Sodium hydroxide
4 - CHEMICAL METAL REMOVAL

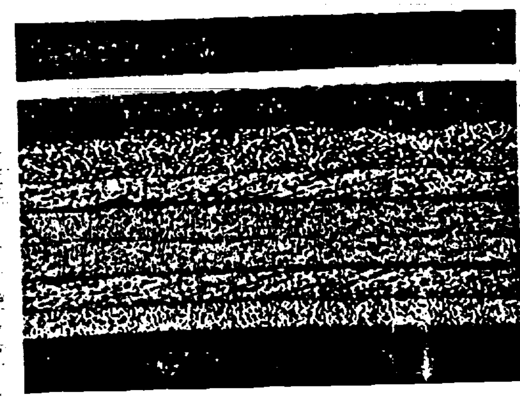
COMPOSITE TUBE WITH Al FOIL COATING

P75/934 (+60,-60,0,0,-60,+60)



COMPOSITE TUBES

2 INCH DIAMETER



TUBE CROSS-SECTION

CLASSES OF ADVANCED SPACE COMPOSITES

Desirable Characteristics
- High Stiffness
- Light Weight
- Dimensional Stability
- Space Durable

Polymer Matrix Composites:
- P75/977
- P100/PEEK
- P100/P1700
- Gr/LCP

Metal Matrix Composites:
- P100/Mg
- P120/Al
- AMMC's

Ceramic Matrix Composites:
- Gr/Glass
- SiC/SiC
- SiC/Si_3N_4

Carbon-Carbon Composites:
- P100/Pitch
- P100/CVI

THRUST(S) SUPPORTED

- SCIENCE
- EXPLORATION
- PLATFORMS

OBJECTIVE:

Develop lubricants, mechanical components, design and test methodology for long-life space mechanical systems

- Liquid and solid lubricants
- Friction and wear models
- Life prediction models
- Advanced mechanical concepts

JUSTIFICATION

- Recent bearing and deployment system failures
- No program in the agency focused on space mechanisms
- Data base inadequate for current problems (20+ yrs old)
- 10+ year mechanical life in space can not be assured- space station requirements up to 30 years

MATERIALS & STRUCTURES

(R&T Base FY 1993 Augmentation)

STRUCTURAL CONCEPTS

SPACE MECHANISMS

PAYOFF

Concepts for mision enabling long-life (>10 years) mechanisms

State-of-the-art technology base for future designs

National resource for addressing future space mechanism problems

PRODUCTS (FY 1993 - FY 1996)

Accelerated life test methodology

Low-vibration, long-life (>10 year) bearing concept for 500-2000 RPM by FY 1995 - FY 1996

Non-contaminating space lubricant with +10 year life

CENTERS: LeRC (+TBD)

AUGMENTATION (TOTAL $K)

FY 1993	500
FY 1994	750
FY 1995	1000
FY 1996	1250
FY 1997	1500

MAJOR FACILITIES: None

MATERIALS AND STRUCTURES DIVISION

OAET

STRUCTURAL CONCEPTS

SPACE MECHANISMS

CURRENT PROGRAM

- $60 K (Net) at LeRC directed toward tribology - fundamental friction and wear studies
- $500 K augmentation planned for FY 1992 to begin space mechanisms program

STATE-of-the-ART

- Bearing systems designed for 2 years - hope for 5 years
- Liquid liquid lubrucants breakdown and/or outgas - can contaminate sensitive instruments
- Solid lubricants limited to 1 million cycles
- Limited pointing accuracy and life due to friction noise
- Design of gears, drives, bearings, actuators etc. all based on past experience - improvements and specialization accomplished empirically

MATERIALS AND STRUCTURES DIVISION

O.A.E.T

STRUCTURAL CONCEPTS

SPACE MECHANISMS

TECHNOLOGY NEEDS

- Long-life, non-contaminating liquid lubricants
- Durable solid film lubricants
- Long-life, low-torque bearing
- Long-life high-temperature mechanisms (1200 Centigrade)
- Long-live cryogenic mechanisms (2.6 Kelvin)
- Models of dynamic bearing behavior
- Integrated lubrication/mechanism design methods
- Accelerated test methods
- Life prediction methodology

MATERIALS AND STRUCTURES DIVISION

O.A.E.T

STRUCTURAL CONCEPTS

SPACE MECHANISMS

PERSPECTIVE

- 30 METSAT - TIROS satellites launched from 1958 to present
- 10 more scheduled to be launched by 2004
- Each satellite carries:
  - 11 different instruments (6 with mechanisms)
  - 10 tape transports
  - 22 motors
  - About 190 bearings
- Goddard Spaceflight Center has approximately 1000 reported lubricant problems on record dating from 1966

STRUCTURAL CONCEPTS

SPACE MECHANISMS

TECHNOLOGY NEEDS - MEDUIM SPEED BEARING (FIRST FIVE YEAR EMPHASIS)

- Bearing with 10+ year endurance life
- Non-contaminating liquid bearing
- Understand failure modes and space environmental effects on performance and life
- Accelerated tesing and life prediction methodology
- Improved lubricant supply
- Reduced bearing mechanical noise (jitter) for improved pointing accuracy
- Generic technology data base
  - Design concept selection
  - Material and lubricant selection

SPACE MECHANISMS REQUIRING LUBRICATION

- Gyroscopes
- Momentum Wheels
- De-Spin Mechanisms
- Gears
- Electrical Slip Rings
- Small Motors
- Hatches
- Valves
- Tape Recorders
- Relays
- Timing Instruments

SPACE ENVIRONMENTAL FACTORS IN LUBRICATION

- Weightlessness: Allows fluids to creep away from bearing.
- Vacuum: Evaporation and loss of lubricant supply.
- Radiation: Atomic oxygen, solar wind, ultra-violet light.

  Leads to degradation of lubricant properties.
- Requires specialized oils, greases, thin solid films and self-lubricating bearing materials, i.e., strong plastic composites.

MATERIALS & STRUCTURES

(R&T Base FY 1993 Augmentation)

SPACE STRUCTURES

SPACE WELDING AND BONDING

THRUST(S) SUPPORTED

- Operations
- Exploration

OBJECTIVE:

Develop advanced joining processes to enable construction, repair and fabrication of structures in orbit and on planetary surfaces:

- Metals
- Ceramics
- Organic materials
- Dissimilar materials

RATIONALE

Very limited study of joining processes for space operations

Fundamental understanding required before focused process development

In-space operations and planetary surface operations all likely to involve some construction and repair

PAYOFF

- Greater design options for space operations
- Improved safety through repair
- Efficient space joining methods with minimal or no (automated) EVA

PRODUCTS (FY 1993 - FY 1996)

FY94: Demonstrate long linear joining of thin and thick materials using plasma arc welding

FYXX: Methods for real-time weld monitoring and NDE

Space curable non-metallic joining method

CENTERS

MSFC, LaRC

AUGMENTATION	TOTAL ($K)
FY 1993	300
FY 1994	400
FY 1995	450
FY 1996	500
FY 1997	600

CofF: None

SPACE STRUCTURES

SPACE WELDING AND BONDING

OAET — MATERIALS & STRUCTURES

CURRENT PROGRAM

- $100K (net) of Exploration Technology Program -- In-Space Assembly and Construction (ISAAC) at MSFC limited to automatic plasma arc tube welding
  - •• Small vacuum welding chamber planned by FY 1993
  - •• Validation of tube welding process planned by FY 1995

STATE-OF-THE-ART

- Soviets have over 20 years in-space experience with hand operated electron-beam welders--will install in MIR in 1992
- Electron-beam penetration and brazing tests conducted on aluminum, tantalum, and stainless steel on Skylab mission in 1973
- Basic tube welding experiments conducted on KC-135
- No bonding processes demonstrated for operations in space

SPACE STRUCTURES

SPACE WELDING AND BONDING

OAET — MATERIALS & STRUCTURES

TECHNOLOGY NEEDS

- Systematic evaluation of optional welding processes including:
  - •• Laser welding
  - •• Inert gas welding
  - •• Explosive welding
  - •• Cold welding
  - •• Brazing
- Space durable/curable bonding materials
- Innovative in-space joining methods for metal and non-metals
- Improved modeling methods for welded and bonded joints
- NDE and life prediction methodology

WELDED JOINTS - CLASSIFICATION
(Basic Advantages)

- **TUBULAR STRUT**
  - High Strength, Low Mass
  - Low Dimensional Accuracy Requirements
  - Simple Welding Mechanism
- **PIPES/DUCTS**
  - Hermetic Seal
  - Simple Welding Mechanism
- **SKIN/TANK**
  - Hermetic Seal
- **SEMI-MONOCOQUE STRUCTURES**
  - High Strength, Low Mass
  - Low Dimensional Accuracy Requirements
- **REPAIR/CONTINGENCY (Manual)**
  - Flexibility

NASA

WELDING PROCESSES UND CONSIDERATION

GTA/PLASMA		
	Operational Simplicity Low Risk to Operator Large Basis of Industrial Experience	Vacuum Operation Unproven Vapor Contamination
ELECTRON BEAM		
	Vacuum Compatibility High Power Densities Possible	Safety Considerations More Complex Power Supply Critical Joint Fitup Reqts.
LASER		
	Portability High Power Densities Possible	Low Power Efficiency Safety Considerations Critical Joint Fitup Reqts.
BRAZING		
	Self-Contained Simplicity Good Capillary Action	Lower Strength Heat Source Undefined

WELDED JOINTS - CLASSIFICATION (Basic Advantages)

- **TUBULAR STRUT**
  - High Strength, Low Mass
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  - Simple Welding Mechanism
- **PIPES/DUCTS**
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- **REPAIR/CONTINGENCY (Manual)**
  - Flexibility

MATERIALS & STRUCTURES

(R&T Base FY 1993 Augmentation)

DYNAMICS OF FLEXIBLE STRUCTURES

ADVANCED TEST TECHNIQUES

THRUST(S) SUPPORTED

- Space Platforms
- Space Science

OBJECTIVE:

Developcapability to predict, design, and verify advanced space platform structures for on-orbit dynamic response when full-scale, integrated ground tests are impractical.

RATIONALE

Many future NASA spacecraft are so large, and some of such high precision, that full-scale ground testing is not practical due to size and gravitational loads.

Techniques are needed for using scale model ground tests to predict the on-orbit structural dynamics behavior of large, multi-component, space structures.

PAYOFF

Ground-based qualification of future spacecraft

Accurate model for predicting on-orbit structural dynamic response

PRODUCTS (FY 1993 - FY 1996)

FY93 Experimental verification of MBCT method

FY XX Develop multi-body flexible panel maneuvering/unfolding experiment

FY XX Develop analysis and test procedures for reliably deployable integrated structural systems

CENTERS

JPL, LaRC

AUGMENTATION	TOTAL ($K)
FY 1993	500
FY 1994	950
FY 1995	1200
FY 1996	1500
FY 1997	1600

CofF: None

DYNAMICS OF FLEXIBLE STRUCTURES
ADVANCED TEST TECHNIQUES

OAET — MATERIALS & STRUCTURES

CURRENT PROGRAM

- Hybrid scale techniques for truss structures
- Advanced suspension systems for ground testing
- Middeck Active Control Experiment
- Artificial boundary conditions for support of ground-tested structures

STATE-OF-THE-ART

- Ground testing and analysis of complete, full-scale system when possible
- Ground testing and analysis of full-scale components
- Component mode synthesis to analytically predict on-orbit dynamic response
- Significant effect on uncertainty of design and test requirements and margins
- Multi-Boundary Condition Test (MBCT) technique to verify analytical models

DYNAMICS OF FLEXIBLE STRUCTURES
ADVANCED TEST TECHNIQUES

OAET — MATERIALS & STRUCTURES

TECHNOLOGY NEEDS

- Scale modeling methodologies for ground testing
- Component test/analysis procedures for determining and predicting on-orbit dynamic performance
- Verified advanced test methodology for space structures incapable of being tested, fully assembled, in earth's gravity field
- Techniques for predicting behabior of full scale space-based structure from results of subcomponent and subscale ground-based tests

THRUST(S) SUPPORTED

- Space Science
- Space Platforms

OBJECTIVE:

Develop sensors, actuators and control techniques and integrate into adaptive structual systems:
- precision motion control
- space structure vibration control
- robotic assembly of space structures
- vibration isolation

PAYOFF

Focused effort has potential to significantly improve the reliability/performance of precision space-based antennas and trusses and relax ground test requierments

PRODUCTS (FY 1993 - FY 1996)

FY93: Materials characterization of new sensors and actuators.

FY94: Adaptive structures testbed

FY96: Candidate embedded sensors and actuators for microgravity experiments and precision control.

MATERIALS & STRUCTURES

(R&T Base FY 1993 Augmentation)

DYNAMICS OF FLEXIBLE STRUCTURES

ADAPTIVE MATERIALS AND STRUCTURES

RATIONALE

Large space-based antennas and trusses that require precise shape control to very small small tolerances (μm) will require fine control possible only by a distributed system of sensors and actuators

Microgravity experiments will require smart actuators capable of providing isolation from the vibration inherent to manned spacecraft

CENTERS

JPL, LaRC

AUGMENTATION	TOTAL ($K)
FY 1993	200
FY 1994	800
FY 1995	1350
FY 1996	1900
FY 1997	2500

CofF: None

DYNAMICS OF FLEXIBLE STRUCTURES
ADAPTIVE MATERIALS AND STRUCTURES

OAET — MATERIALS & STRUCTURES

CURRENT PROGRAM

- Integrating SOA sensors and piezoelectric/electrostrictive materials to develop active members
- Demonstrating feasibility of active damping and precision static control on Precision Segmented Reflector (PSR) and Control - Structures Interaction (CSI) programs

STATE-OF-THE-ART

- 10 year old fiber optic sensor program capability in many areas (pressure, force, temperature, photo/magneto/electrical fields, etc.)
- Actuator technology (piezoelectrics, active truss members, shape memory alloys) demonstrated but not space qualified
- Demonstrated capability of active damping and precision static control

ADAPTIVE MATERIALS AND STRUCTURES

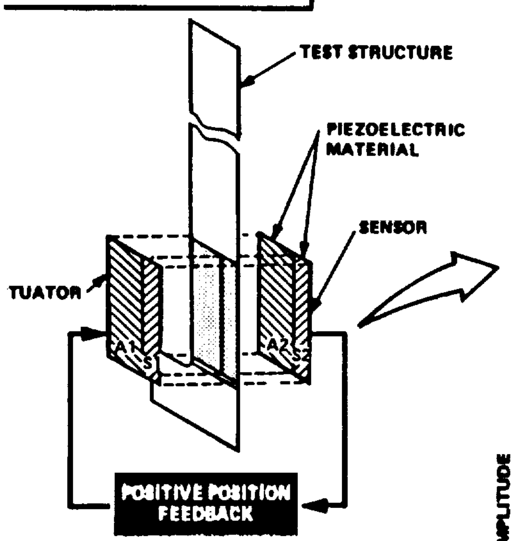
TECHNOLOGY NEEDS

- Development of new sensor and actuator materials for space operational temperatures (100Kelvin)
- Sensor and actuator fabrication and embedding techniques
- Material characterization of sensors and actuators in active members and structural systems
- Space qualification of active members and adaptability of concepts for flight hardware
- Multi-input/multi-output controllers for distributed sensor/ actuator systems
- System level integration

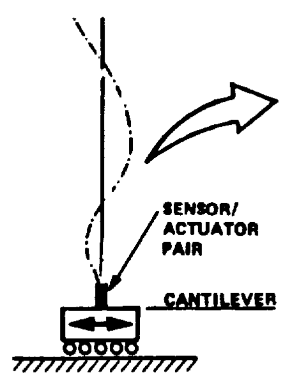
JPL

VIBRATION SUPPRESSION BY PIEZOELECTRIC STIFFNESS CONTROL

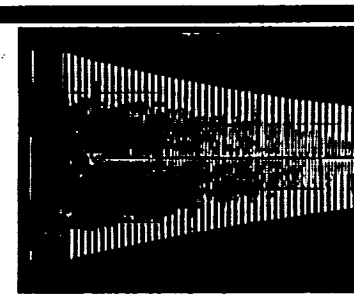
CHALLENGES
- MULTI-MODE SUPPRESSION
- USE INTERNAL FORCES ONLY
- ROBUST OPERATION



PIEZOELECTRIC SENSORS AND CONTROL ACTUATORS



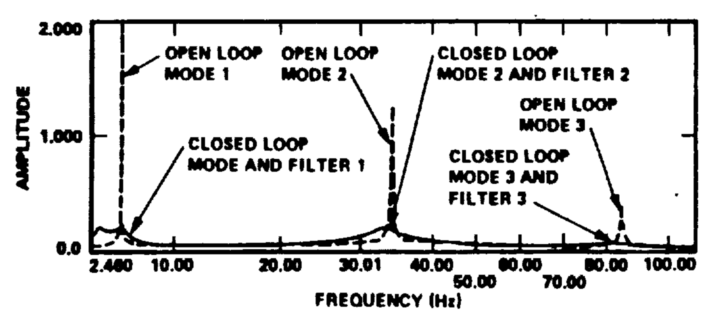
MULTI-MODE BASE EXCITATION



CLOSED LOOP vs. OPEN LOOP FREE DECAY FOR MODE NO. 1

.CCOMPLISHMENTS

EMONSTRATION OF SINGLE SENSOR/ACTUATOR EVICE CONCEPT FOR MULTI-MODE VIBRATION JPPRESSION



FREQUENCY RESPONSE PLOT – MODES 1 THROUGH 3

THRUST(S) SUPPORTED

- Space Platforms
- Operations

OBJECTIVE:

Develop a comprehensive capability to model the large-angle, transient dynamic response of multi-body spacecraft for final verification of load alleviation and control schemes

PAYOFF

Comprehensive modeling tool for dynamics of multi-body spacecraft

Assured stability and improved performance

PRODUCTS (FY 1993 - FY 1996)

FY 94: Analysis capability for design and assessment of multiple interacting control systems on a flexible spacecraft

FY 94: Design approaches and prototype hardware for load alleviation and isolation

FY 94 Analysis capability for nonlinear slosh of fluids in low gravity

MATERIALS & STRUCTURES

(R&T Base FY 1993 Augmentation)

DYNAMICS OF FLEXIBLE STRUCTURES

MULTI-BODY AND NONLINEAR DYNAMICS

RATIONALE

Uncertainties in modelling can lead to conservatism in dynamic loads analysis, unexpected interaction of control systems of the spacecraft and flexible manipulator and appendages, and potential failures to maintain fuels in configuration for transfer.

CENTERS

LaRC

AUGMENTATION	TOTAL ($K)
FY 1993	200
FY 1994	350
FY 1995	500
FY 1996	600
FY 1997	800

CofF: None

DYNAMICS OF FLEXIBLE STRUCTURES
MULTI-BODY AND NONLINEAR DYNAMICS

OAET — MATERIALS & STRUCTURES

CURRENT PROGRAM

- Large angle slewing motion of simple flexible manipulators.
- MODE - Middeck 0-G Dynamics Experiment
- MACE - Middeck Active Control Experiment

STATE-OF-THE-ART

- LATDYN - Large Angle Transient DYNamics modeling tool
- DADS - modal-based modeling tool

MULTI-BODY AND NONLINEAR DYNAMICS

TECHNOLOGY NEEDS

- Comprehensive ability to model the dynamics of flexible multi-body spacecraft
- Approaches to dynamic load limiting and alleviation
- Simplified yet nonlinear model of fluid dynamic behavior and slosh
- Verified ability to predict and control on-orbit dynamics deployment of folded flexible structures

MATERIALS & STRUCTURES

(R&T Base FY 1993 Augmentation)

DYNAMICS OF FLEXIBLE STRUCTURES

VIBRATION ISOLATION

THRUST(S) SUPPORTED

- Space Science
- Space Platforms

OBJECTIVE:

Develop passive and active techniques for isolating:

- On-board acoustic and vibration sources (e.g., pumps, motors, treadmills)
- Vibration sensitive instruments and equipment (e.g., micro-gravity experiments, scanners)

PAYOFF

Enable conduct of microgravity experiments

Enable 100X increase in pointing accuracy

Reduce crew stress and fatigue

PRODUCTS (FY 1993 - FY 1996)

FY95: Flight qualified demonstration of microgravity experiment isolation (e.g., GASCAN)

FY96: Design adaptation for transition to space station

RATIONALE

Microgravity experiments and critical sensors:

- Milli-g environment expected
- Micro-g environment required

Noise and vibration affect crew performance

CENTERS

LeRC, LaRC

AUGMENTATION	TOTAL ($K)
FY 1993	200
FY 1994	550
FY 1995	850
FY 1996	1000
FY 1997	1300

CofF: None

DYNAMICS OF FLEXIBLE STRUCTURES

VIBRATION ISOLATION

OAET — MATERIALS & STRUCTURES

CURRENT PROGRAM

- Ground-based 6-DOF actively controlled magnetic isolation platform and magnetic bearing Proof of Concept studies
- Ground-based active source reaction load isolation platform Proof of Concept study for large/random excitation
- Evaluation of 1-DOF reactionless positioning mechanism for microgravity experiments (no longer funded)
- Development of robotic manipulator technology for extremely smooth, jitter-free positioning and base reaction control (no longer funded)

STATE-OF-THE-ART

- Power efficient lightweight electronics for magnetic suspension systems are available and have begun to be evaluated in lab tests
- Space station vibration environmental design goals cannot be met with current technology
- Large payload manipulation produces large and relatively uncontrolled spacecraft reactions
- Active vibration isolation concepts are evolving in the lab but have not been flight demonstrated

DYNAMICS OF FLEXIBLE STRUCTURES

VIBRATION ISOLATION

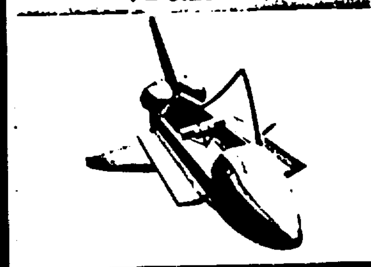
OAET — MATERIALS & STRUCTURES

TECHNOLOGY NEEDS

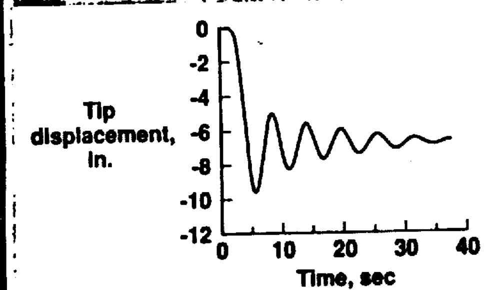
- Power and weight efficient magnetic suspension actuators for isolation systems
- "Smart" actively controlled devices for isolation of source vibrations (e.g., pumps, motors, treadmills) to minimize effects on crew performance
- "Smart" mechanisms with active control strategies for isolating critical sensors and equipment
- Isolation of precision scanning devices from spacecraft-borne disturbances
- Extremely precise manipulators for smooth, jitter-free experiment positioning in microgravity labs on space station and free-flying platforms
- Space-based demonstrations to correlate with ground-based tests
- Space demonstrated (quantifiable) vibration isolation design approach database as basis for future systems development

ACTIVE VIBRATION CONTROL OF THE SHUTTLE RMS

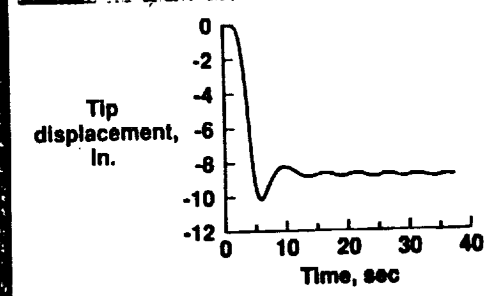
Typical RMS flexible mode
f = 0.26 Hz



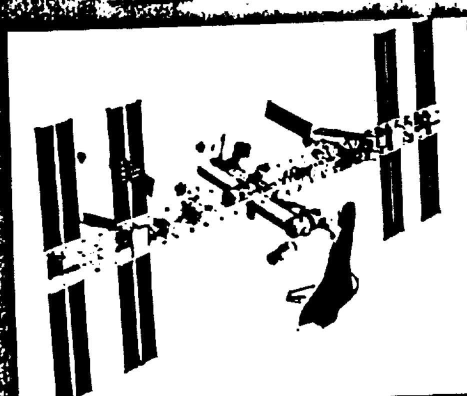
TIP response
without active vibration control



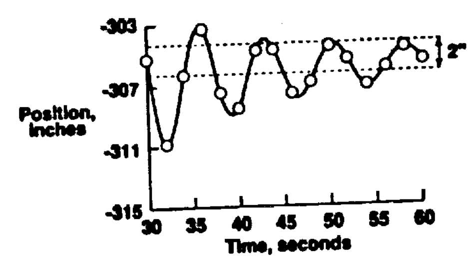
TIP response
with active vibration control



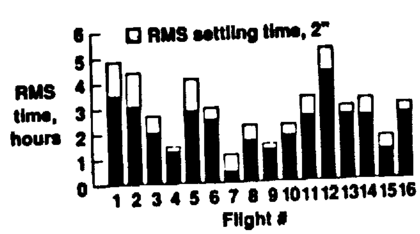
POTENTIAL SPACE STATION ASSEMBLY BENEFITS DUE TO CSI (Timeline)



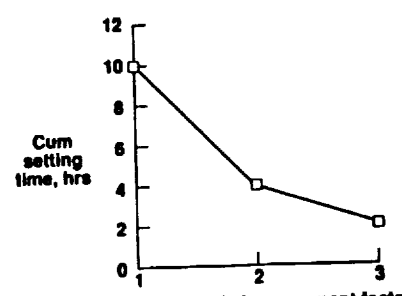
Draper RMS Simulator response
Payload 3500 lbs

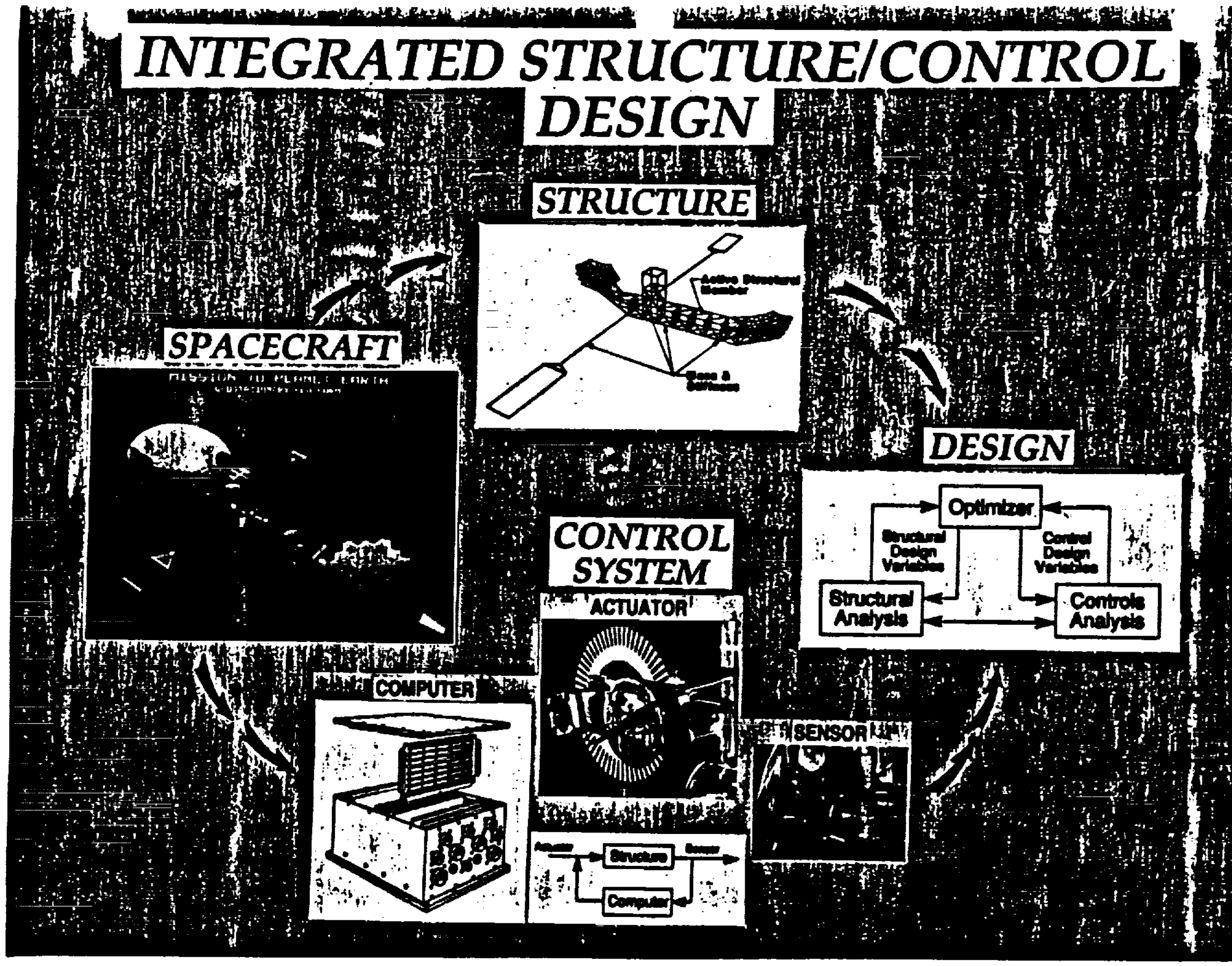


RMS settling time



Potential CSI benefits




INTEGRATED STRUCTURE/CONTROL DESIGN
STRUCTURE
SPACECRAFT
DESIGN
Optimizer
Structural Design Variables
Control Design Variables
Structural Analysis
Controls Analysis
CONTROL SYSTEM
ACTUATOR
COMPUTER
SENSOR
Structure
Computer

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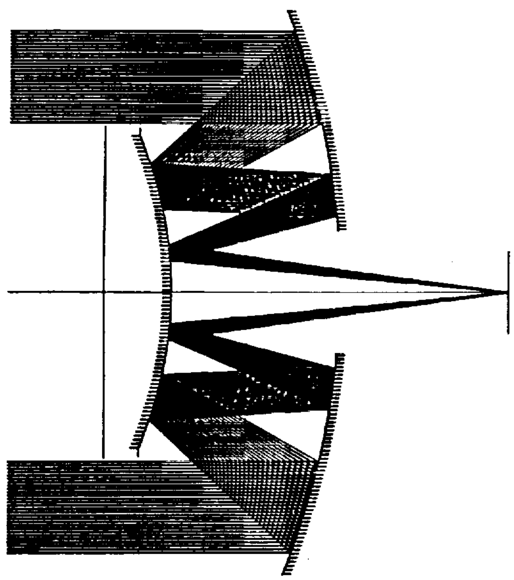


OPTICS TECHNOLOGY BASE R&T PROGRAM OVERVIEW

Daniel R. Coulter

June 26, 1991

OPTICS TECHNOLOGY BASE R&T PROGRAM OVERVIEW

NASA is studying a number of advanced optical systems concepts to achieve a variety of science mission goals. Most of these concepts require significant advancements in optics technology. New optics modelling tools are needed to guide development of ultralow scattering optical systems and to improve the accuracy of optics analysis such as that done for image optimization. New materials such as silicon carbide, carbon-carbon or novel "zero expansion" ceramics could provide the technology for lightweight high precision optics. New coating materials such as amorphous metals or doped semiconductors could provide broadband, low scattering, low thermal background mirrors. New optics fabrication techniques such as ion polishing or plasma assisted chemical etching will enable a whole new class of optics which have never been considered in the past because there was no way to figure and polish these complex geometric shapes with conventional methods. New optical test techniques are needed to simplify the procedures required to verify optical performance, and to provide faster and less costly ways to quickly check optical designs. Wavefront sensing and control technologies will enable the use of large lightweight optical systems in space. Advanced sensor optics technology such as binary optics and tunable filters will enable a wide range of new instruments to fully utilize the capabilities of new large aperture optical systems. Development of these and other advanced optics technologies will enable new spatial and spectral resolution capabilities for space and lunar based instruments.

A new base program of research and technology development is needed enable advanced optical systems. The program structure contains six major program elements: Optics Modelling, Optical Materials and Coatings, Advanced Optics Fabrication, Optical Test, Wavefront Sensing and Control, and Sensor Optics Technology. The individual activities in each element will pursue key optics technology issues that could provide revolutionary advancements in capability. The research started in this program will provide concepts and products that will be transferred directly to focused technology programs and users and will provide NASA with the in-house "hands-on" experience needed to successfully carry out many of the advanced science missions now under study. The program is also designed to coordinate with and leverage IR&D programs and developments in government, industry, and academia.

OPTICS TECHNOLOGY BASE R&T PROGRAM

PRESENTATION AGENDA

- Introduction
- Program Overview
- Backup Information

INTRODUCTION

OPTICS TECHNOLOGY BASE R&T PROGRAM

OBJECTIVE AND JUSTIFICATION

PROGRAM OBJECTIVE:

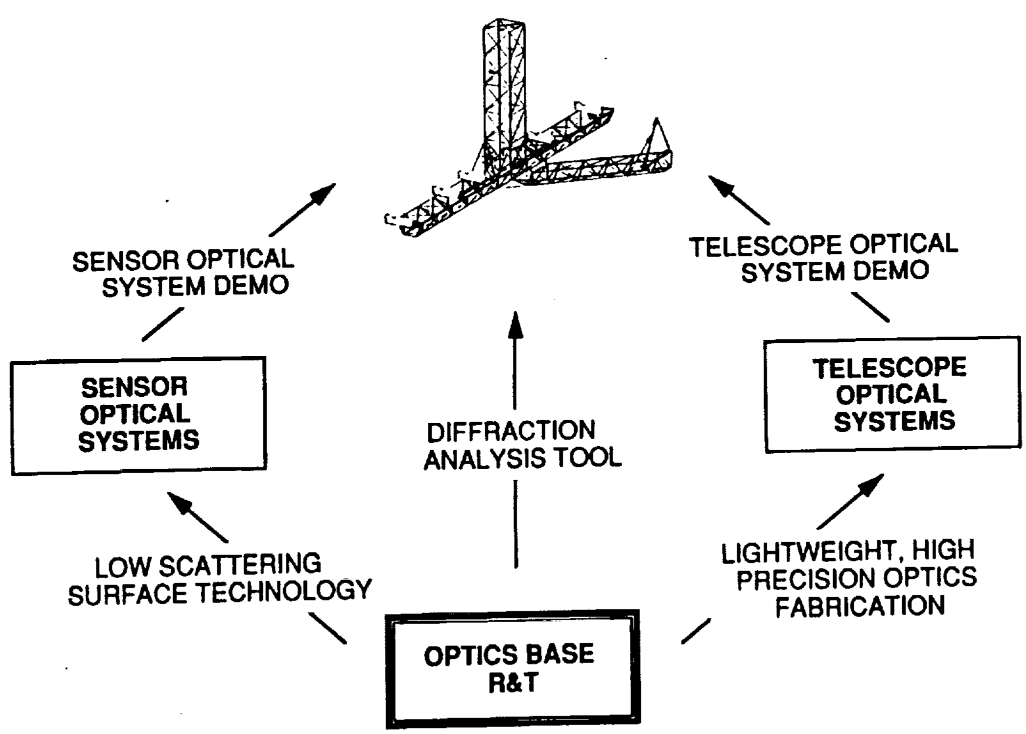
Develop fundamental technology to enable analysis, design, fabrication, testing and control of advanced space optical systems

JUSTIFICATION:

- NASA needs basic optics technology to support numerous future space and lunar missions currently in the study/planning phase
- OAET Base R&T Optics Program will develop technology to meet the needs of these future missions
- Base R&T Optics program will provide the higher risk, longer lead, innovative technology which the related Focused programs build upon
- On-going technology program can respond to needs of current flight programs (e.g. SIRTF)
- OAET Base R&T Optics Program is strongly supported by technology users in OSSA and the science community

OPTICS TECHNOLOGY BASE R&T PROGRAM

OPTICS TECHNOLOGY PROGRAM RELATIONSHIPS (EXAMPLE)



OPTICS TECHNOLOGY BASE R&T PROGRAM

OAET, OSSA AND SCIENCE COMMUNITY INPUTS TO PROGRAM PLAN

- Exploration Technology Program Plan: Lunar and Mars Science Technology Summary, November 16, 1990
- Industry Tours, February-April 1991
- Large Filled Aperture Telescopes in Space Workshop, March 4-5, 1991
- ASTROTECH 21 Optics Technology Workshop, March 6-8, 1991
- The Decade of Discovery in Astronomy and Astrophysics (Bahcall Report), March 18, 1991
- Exploration Technology Planning Update, March 19, 1991
- OSSA Division Technology Needs (Draft), April 12, 1991
- Towards Other Planetary Systems (TOPS) Technology Needs Identification Workshop, April 22-24, 1991
- Technologies for Advanced Planetary Instruments Workshop, May 8-10, 1991

PROGRAM OVERVIEW

OPTICS TECHNOLOGY BASE R&T PROGRAM
PROGRAM STRUCTURE

OPTICS TECHNOLOGY BASE R&T

OPTICAL MATERIALS & COATINGS
- LOW MASS, HIGH PRECISION MATERIALS
- STABLE MATERIALS FOR HOSTILE ENVIRONMENTS
- CRYOGENIC MATERIALS
- LARGE AREA COATINGS
- LOW SCATTER COATINGS & MASKS
- X-RAY/FAR IR COATINGS

WAVEFRONT SENSING AND CONTROL
- WAVEFRONT SENSORS
- ACTUATORS
- ACTIVE OPTICS DESIGNS
- METROLOGY TECHNIQUES
- SYSTEM CONTROL ARCHITECTURE

OPTICS FABRICATION & PROCESSING
- IMPROVED REPLICATION TECHNIQUES
- POLISHING SCIENCE
- SHAPING & FIGURING
- SEGMENTED OPTICS
- CRYO OPTICS
- INTEGRATED OPTICAL ASSEMBLIES
- X-RAY OPTICS

OPTICS TESTING
- SURFACE ROUGHNESS
- IMAGE QUALITY ASSESSMENT
- STRAY LIGHT & SCATTERING
- FIGURE MEASUREMENT
- ALIGNMENT
- RADIOMETRY
- CRYOGENIC TEST METHODOLOGY
- END-TO-END TESTING METHODOLOGY

OPTICS MODELING
- SCATTERING THEORY
- DIFFRACTION ANALYSIS
- STRAY LIGHT ANALYSIS
- THERMAL BACKGROUND
- OPTIMIZATION SCHEMES
- END-TO-END MODELING

SENSOR OPTICS
- ADVANCED GRATINGS
- TUNABLE FILTERS
- X-RAY/FAR IR OPTICAL COMPONENTS
- HIGH DYNAMIC RANGE IMAGING COMPONENTS
- INTEGRATED OPTICS
- INTERFERO-METER OPTICS

OPTICS TECHNOLOGY BASE R&T PROGRAM
TECHNOLOGY CHALLENGES AND STATE-OF-THE-ART

TASK ELEMENT	TECHNOLOGY CHALLENGES	STATE-OF-THE-ART
Optical Materials & Coatings		
• areal density	1-10 Kg/sq.m	40-200 Kg/sq. m (vis.)
• dimensional stability	1-10 ppb	0.1-1 ppm
• large area coatings	<0.1% uniformity	3-10% uniformity
• x-ray reflect. coatings	broadband	narrowband
Wavefront Sensing & Control		
• metrology	10pm, space based	1nm, ground based
• actuators	low power, 100°K, ≤1nm	300°K, 0.1μm
• deformable mirrors	space based, 100°K	ground based, 300°K
• control architecture	highly parallel	serial, digital
Optics Fabrication & Processing		
• figure	≤1nm RMS,single cycle, deterministic	10nm RMS, multiple cycles
• μ-roughness	≤1Å RMS	5-10Å RMS
• replication	high accuracy	emerging processes
• innovative concepts	bring to maturity	concepts exist

OPTICS TECHNOLOGY BASE R&T PROGRAM

TECHNOLOGY CHALLENGES AND STATE-OF-THE-ART

TASK ELEMENT	TECHNOLOGY CHALLENGES	STATE-OF-THE-ART
Optics Testing		
• figure measurement	<1nm, aspheric	10nm, limited aspheric
• scattering	0.1-1000μm, angles≤ 0.001°	0.4-25μm, angles≥0.1°
• radiometry	0.1% accuracy	1-5% accuracy
• end-to-end testing	practical methodology	piecewise testing
Optics Modeling		
• end-to-end simulation	accurate, efficient tools	piecewise
• optimization	merit functions, practical tools	inefficient tools
• diffraction	comprehensive	emerging models
• scattering	rigorous models	statistical models
Sensor Optics		
• imaging	UV/far IR components	visible, near IR
• filters	narrowband, tunable	fixed wavelength
• straylight suppression	0.1ppb	0.1-1ppm
• windows	x-ray-/EUV	very limited

OPTICS TECHNOLOGY BASE R&T PROGRAM

PROGRAM IMPLEMENTATION

- NASA to invest $0.7-3M/year in basic optics R&D
- Form an Optics Technology Working Group:
  - include technologists and scientists, NASA and non-NASA
  - identify most critical optics technology needs
  - identify existing resources and coordinate efforts between various centers, government agencies and other OAET programs
  - review implementation plans for specific activities
- Utilize partnerships with industry and academia

OPTICS TECHNOLOGY BASE R&T PROGRAM

SCHEDULE & BUDGET

Target Milestones

93 - Theory relating microscopy (STM, AFM) data to light scattering

94 - "Zero CTE" (≤0.01ppm/K) materials for ≤100°K application

95 - Low power, low temperature (≤100°K), ≤ 1nm accuracy actuator

96 - Absolute figure measurement to ≤ 1nm (≥1m optics)

97 - Large area (≥ 1m) uniform (≤ 0.1%) broadband reflecting coating

98 - ≤ 1nm RMS figure for ≥ 1m optic

99 - High dynamic range (10^{10}) visible imaging proof-of-concept demo

($K)

Budget	FY 93	FY 94	FY 95	FY 96	FY 97
Current	0	0	0	0	0
Planned	3000	4500	5000	5250	5500
3X	700	1400	2100	2400	3000

OPTICS TECHNOLOGY BASE R&T PROGRAM

SUMMARY

- NASA has an increasing need for optics technology to support future missions
- OAET Base R&T Optics program to meet this need will span fundamental theory, analysis, simulation and proof-of-concept demonstration
- Base Optics program will focus on higher risk, longer lead, innovative technologies which Focused Optics programs build on
- Partnerships with industry and academia is essential

BACKUP MATERIALS ON SPECIFIC TASK ELEMENTS

OPTICS TECHNOLOGY BASE R&T PROGRAM

OPTICAL MATERIALS AND COATINGS

OBJECTIVE:

DEVELOP HIGH PERFORMANCE MATERIALS AND COATINGS WITH LOW MASS, UNIFORMITY, STABILITY AND REQUIRED FUNCTIONAL PROPERTIES FOR FUTURE NASA SPACE OPTICAL SYSTEMS

SPECIFIC NEEDS:

- LOW MASS, GLASS, CERAMIC AND COMPOSITE MATERIALS WITH THERMAL AND TEMPORAL STABILITY AT 100°K
- MATERIALS COMPATIBLE WITH ADVANCED POLISHING, FIGURING AND COATING TECHNIQUES SUCH AS ION AND PLASMA PROCESSING
- ADVANCED MATERIALS SUCH AS SILICON CARBIDE FOR CRYOGENIC OPTICS, SUPPORT STRUCTURES AND ASSEMBLIES
- MATERIALS SUCH AS AMORPHOUS METALS OR METAL NITRIDES FOR BROADBAND, LOW SCATTERING, REFLECTIVE COATINGS
- COATINGS TAILORED FOR SUCH THINGS AS BROADBAND X-RAY REFLECTIVITY, STRAY LIGHT CONTROL IN THE SUBMILLIMETER REGION AND THERMAL BACKGROUND CONTROL IN IR REFLECTORS

OPTICS TECHNOLOGY BASE R&T PROGRAM

OPTICAL MATERIALS AND COATINGS

STATE OF THE ART:

- SIGNIFICANT GLASS TECHNOLOGY EXISTS
- MATERIALS DESIGNED FOR 300K APPLICATIONS
- LACK OF STABLE, HOMOGENEOUS, LOW MASS MATERIALS
- DETAILED UNDERSTANDING OF ION PROCESSING LACKING FOR MOST MATERIALS
- LIMITED DATA ON MATERIALS FOR CRYOGENIC APPLICATIONS
- NARROWBAND, LOW SCATTER, DIELECTRIC COATINGS EXIST
- LACK OF GOOD COATINGS FOR X-RAY AND FAR IR APPLICATIONS

OTHER DEVELOPMENTAL EFFORTS:

- DOD EFFORTS FOCUSED ON SPACE BASED LASER AND SURVEILLANCE APPLICATIONS
- SEVERAL HIGH QUALITY UNDERFUNDED EFFORTS AT UNIVERSITIES
- PROPRIETARY EFFORTS IN US INDUSTRY, HOWEVER, NOT GENERALLY FOCUSING ON NASA UNIQUE NEEDS

OPTICS TECHNOLOGY BASE R&T PROGRAM

WAVEFRONT SENSING AND CONTROL

OBJECTIVE:

DEVELOP THE TECHNOLOGY FOR WAVEFRONT SENSORS AND CONTROL SYSTEMS FOR LARGE SEGMENTED OPTICS AND ACTIVELY CONTROLLED OPTICAL SYSTEMS IN SPACE

SPECIFIC NEEDS:

- PICOMETER SCALE PATHLENGTH AND WAVEFRONT MEASUREMENT METHODOLOGY
- LOW POWER, LOW TEMPERATURE, DURABLE SENSORS AND ACTUATORS UTILIZING, FOR EXAMPLE, PHASE SWITCHING CERAMICS
- ACTIVE FIGURE CONTROL OF REFLECTOR PANELS WITH IMBEDDED SENSORS AND ACTUATORS
- REMOVAL OF STRUCTURAL VIBRATIONS TO THE NANOMETER LEVEL BY PASSIVE AND ACTIVE DAMPING METHODS
- HIGHLY PARALLEL CONTROL ARCHITECTURES FOR INTERFEROMETERS AND SEGMENTED OPTICAL SYSTEMS

OPTICS TECHNOLOGY BASE R&T PROGRAM

WAVEFRONT SENSING AND CONTROL

STATE OF THE ART:

- GROUND BASED 1nm METROLOGY SYSTEMS
- PZT, PMN, VOICE COIL ACTUATORS NO WELL DEVELOPED DEVICES WITH SIMULTANEOUS LOW MASS, LOW POWER, LOW TEMPERATURE PERFORMANCE
- GROUND BASED DEMONSTRATIONS OF FIRST GENERATION ACTIVE OPTICS
- LIMITED ACTIVE DAMPING TECHNOLOGY
- COMPLEX, INEFFICIENT CONTROL SYSTEM ARCHITECTURES AND ALGORITHMS

OTHER DEVELOPMENTAL EFFORTS:

- DOD
- EFFORTS IN US AND EUROPEAN UNIVERSITIES
- LIMITED NUMBER OF SPECIALIZED EFFORTS IN INDUSTRY

OPTICS TECHNOLOGY BASE R&T PROGRAM

OPTICS FABRICATION AND PROCESSING

OBJECTIVE:

GAIN FUNDAMENTAL UNDERSTANDING OF THE EFFECTS OF PROCESSING ON OPTICAL COMPONENTS AND DEVELOP OR EXPLOIT NEW CONCEPTS FOR NOVEL OPTICAL FABRICATION TECHNIQUES TO ENABLE MANUFACTURING OF OPTICS FASTER, BETTER AND CHEAPER

SPECIFIC NEEDS:

- RESIDUAL STRESS CONTROL IN REPLICATED COMPOSITE, CERAMIC AND GLASS OPTICS
- FUNDAMENTAL UNDERSTANDING OF THE EFFECTS OF ION FIGURING AND POLISHING ON OPTICAL SUBSTRATES LEADING TO DETERMINISTIC 1nm RMS FIGURING OF LARGE OPTICS
- BASIC UNDERSTANDING OF SUBSURFACE DAMAGE IN POLISHED OPTICS AND TECHNIQUES TO MINIMIZE IT
- CONCEPTS AND TECHNIQUES FOR FABRICATING INTEGRATED OPTICAL ASSEMBLIES (MIRRORS AND SUPPORT STRUCTURES)
- IMPROVED REPEATABILITY IN THE MANUFACTURE OF SEGMENTED OPTICAL ELEMENTS

OPTICS TECHNOLOGY BASE R&T PROGRAM

OPTICS FABRICATION AND PROCESSING

STATE OF THE ART:

- EXTENSIVE EXPERIENCE IN GLASS OPTICS
- SEVERAL NEAR NET SHAPE REPLICATION TECHNIQUES BEING DEVELOPED FOR SEVERAL MATERIALS (Gr/Epoxy, SiC, Be, glass)
- MULTI-STEP ITERATIVE FIGURING PROCESS
- METER CLASS OPTICS WITH FIGURE IN 10nm RANGE AND ROUGHNESS IN 5-10nm RANGE
- ION PROCESSING TECHNIQUES BEING ACTIVELY DEVELOPED BUT DETAILED UNDERSTANDING OF PROCESS IS LACKING
- DESTRUCTIVE TESTS FOR SUBSURFACE DAMAGE
- CONCEPTS FOR INTEGRATED OPTICAL ASSEMBLIES EXIST

OTHER DEVELOPMENTAL EFFORTS:

- SUPPORT FROM DOD IN IN SPECIALIZED AREAS
- SEVERAL US UNIVERSITIES
- EFFORTS AT KODAK, ITEK, HDOS, UTOS,...
- MANY SMALLER EFFORTS

OPTICS TECHNOLOGY BASE R&T PROGRAM

OPTICS TESTING

OBJECTIVE:

DEVELOP NEW METHODS TO CHARACTERIZE, TEST AND VALIDATE PERFORMANCE OF OPTICAL COMPONENTS AND SYSTEMS

SPECIFIC NEEDS:

- HARDWARE AND SOFTWARE FOR ABSOLUTE SURFACE ROUGHNESS MEASUREMENTS USING SCANNING MICROPROBE TECHNIQUES MICROPROBE TECHNIQUES
- METHODOLOGIES FOR ACCURATE IMAGE QUALITY ASSESSMENT AND OPTIMIZATION
- TECHNIQUES FOR CHARACTERIZATION OF SCATTERING FROM LARGE OPTICS AT SUBARCSECOND ANGLES
- TECHNIQUES TO ACCURATELY CHARACTERIZE THE FIGURE OF LARGE ASPHERIC OPTICS TO 1nm
- CRYOGENIC OPTICS TESTING TECHNIQUES
- CALIBRATION STANDARDS FOR ACCURATE RADIOMETRY
- CONCEPTS AND TECHNIQUES FOR END-TO-END TESTING OF LARGE SCALE OPTICAL SYSTEMS

OPTICS TECHNOLOGY BASE R&T PROGRAM

OPTICS TESTING

STATE OF THE ART:

- LIMITED ABSOLUTE SURFACE CHARACTERIZATION CAPABILITY (ROUGHNESS OR FIGURE)
- LACK OF GOOD MERIT FUNCTIONS FOR OPTIMIZATION
- NO NARROW ANGLE SCATTERING CAPABILITY (0.1°)
- GOOD SPHERICAL/NEAR SPHERICAL FIGURE MEASUREMENT (10nm)
- VERY LIMITED FIGURE MEASUREMENT FOR "ODD SHAPED" OPTICS
- LIMITED CRYOGENIC TEST CAPABILITY
- LIMITED HIGH ACCURACY RADIOMETRY
- CONCEPTS FOR IN PROCESS AND END-TO-END TESTING EXIST

OTHER DEVELOPMENTAL EFFORTS:

- CHINA LAKE NAVAL WEAPONS CENTER
- SMALL EFFORTS IN US AND EUROPEAN UNIVERSITIES
- LIMITED NUMBER OF SPECIALIZED EFFORTS IN US INDUSTRY

OPTICS TECHNOLOGY BASE R&T PROGRAM

OPTICS MODELING

OBJECTIVE:

DEVELOP COMPREHENSIVE AND ACCURATE MODELS OF THE PROPAGATION OF LIGHT THROUGH OPTICAL SYSTEMS TO ENABLE OPTIMIZATION AND PREDICTION OF PERFORMANCE

SPECIFIC NEEDS:

- MODEL SURFACE SCATTERING ASSOCIATED WITH A WIDE RANGE OF SPATIAL FREQUENCIES
- TOOLS FOR IMPROVED MODELING OF DIFFRACTION IN COMPLEX OPTICAL SYSTEMS
- IMPROVE ACCURACY OF STRAY LIGHT CALCULATIONS
- MODELING OF THERMAL BACKGROUND IN OPTICAL SYSTEMS
- END-TO-END MODELING CAPABILITIES FOR SYSTEM OPTIMIZATION

OPTICS TECHNOLOGY BASE R&T PROGRAM

OPTICS MODELING

STATE OF THE ART:

- LACK OF COMPREHENSIVE SCATTERING THEORY
- INCOMPLETE DIFFRACTION AND STRAY LIGHT ANALYSIS
- INCOMPLETE THEORY OF THERMOOPTICAL PROPERTIES OF MATERIALS
- EXTENSIVE OPTICAL DESIGN PROGRAMS EXIST
- DETAILED FINITE ELEMENT ANALYSIS EXIST
- MANY IMAGE PROCESSING AND ANALYSIS PROGRAMS EXIST
- FLEDGLING INTEGRATED DESIGN AND OPTIMIZATION SOFTWARE

OTHER DEVELOPMENTAL EFFORTS:

- DOD
- SMALL EFFORTS IN US AND EUROPEAN UNIVERSITIES
- LIMITED NUMBER OF PROPRIETARY EFFORTS IN US INDUSTRY

OPTICS TECHNOLOGY BASE R&T PROGRAM

SENSOR OPTICS

OBJECTIVE:

DEVELOP TECHNOLOGY FOR SENSOR RELATED OPTICAL SYSTEMS TO ENABLE NEW SCIENCE AND TO FULLY UTILIZE CAPABILITIES OF NEW LARGE COLLECTORS OVER EXTENDED SPECTRAL BANDS

SPECIFIC NEEDS:

- BINARY OPTICS (COMBINED REFRACTIVE/REFLECTIVE) TECHNOLOGY
- FAR IR AND UV IMAGING ELEMENTS
- ADVANCED ASPHERIC, HOLOGRAPHIC AND VARIABLE SPACE LINE GRATINGS
- NARROWBAND TUNABLE FILTERS IN UV/VIS/NEAR-IR
- EUV/X-RAY WINDOWS AND COATINGS
- STRAYLIGHT/STARLIGHT SUPPRESSION TECHNIQUES FOR HIGH DYNAMIC RANGE IMAGING SYSTEMS

SENSOR OPTICS

STATE OF THE ART:

- IMMATURE BINARY OPTICS TECHNOLOGY
- LIMITED EUV/X-RAY MATERIALS AND COATINGS
- EXTENSIVE STANDARD GRATING TECHNOLOGY
- NO TUNABLE FILTER TECHNOLOGY
- LIMITED LIGHT SUPPRESSION TECHNOLOGY

OTHER DEVELOPMENTAL EFFORTS:

- SMALL SPECIALIZED EFFORTS IN US AND EUROPEAN UNIVERSITIES AND INDUSTRY

INTEGRATED TECHNOLOGY PLAN
FOR THE CIVIL SPACE PROGRAM

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SAMPLE ACQUISITION, ANALYSIS AND PRESERVATION PROJECT SUMMARY

June 24-28, 1991

Dr. Kim Aaron

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

SAMPLE ACQUISITION, ANALYSIS AND PRESERVATION

OBJECTIVE

Develop component and system level technology to enable the unmanned collection, analysis and preservation of physical, chemical and mineralogical data from the surface of planetary bodies

- **Site and Sample Selection**
- **Sample Acquisition**
- **Sample Analysis**
- **Containment and Preservation**
- **System Design**

TECHNICAL CHALLENGES

- **Site and Sample Selection: remotely locate and identify samples using spectral data**
- **Sample Acquisition: obtain fresh rock, surface and subsurface material and volatiles in harsh environments**
- **Sample Analysis: conduct physical and chemical, mineralogical and engineering data analyses**
- **Containment and Preservation: maintain samples in pristine condition for as long as 3-years for a sample return mission**
- **System Design: Develop compact long-life, physically robust concepts**
- ***Micro-SAAP: miniaturize concepts for use on micro-rovers (proposed new emphasis)***

DELIVERABLES (by fiscal year)

1993 Remote sample imaging between 0.4 and 2.4-micron wavelengths

1995 Automated rock coring
Multi-purpose sample acquisition end-effector
Sample containment concept

1996 Automated regolith coring

1997 Methods for physical/chemical analysis
Environmental control concept

1999 Integrated SAAP testbed for a robotic science mission validated by testbed hardware in a "natural" environment

2003 *Advance mission systems with longer-term durability and enhanced autonomy*

PARTICIPANTS/RESOURCES

JPL, JSC, (ARC)

	93	94	95	96	97
CURRENT	0.0	0.0	0.0	0.0	0.0
"3X"	1.5	5.2	7.0	7.9	9.4
STRATEGIC	2.1	5.3	7.5	9.7	8.0

Thrust:	Science
Key Objective:	Develop the Technologies to Enable the Efficient and Effective Remote In Situ Science on Planetary Surfaces Utilizing Probes, Penetrators and Robotics.
Specific Objective:	Enable Cost-Effective In Situ Science Studies, Robotic Acquisition of Surface and Subsurface Materials Samples, Analysis of Samples, and Return of Selected Samples to Earth, While Meeting All Forward and Back Contamination Requirements.

Target Milestones

Center		
JPL	1991	Breadboard AOTF-based imaging spectrometer 0.4-0.8 um, 1.2-2.4 um
JPL	1991	Breadboard rock coring tool
JPL	1993	Breadboard scoop/tool end effector
JPL	1994	Breadboard AOTF-based imaging spectrometer 0.4-2.5 um
JPL	1994	Breadboard regolith coring tool
JPL	1995	Prototype rock coring tool
JPL	1995	Prototype end effector
JSC	1995	Breadboard containment system
JPL	1996	Breadboard AOTF-based imaging spectrometer 0.4-5 um
JPL	1996	Prototype regolith coring tool
JPL	1996	Breadboard Preparation System
JSC	1997	Breadboard Environmental Control System
JPL	1998	Prototype AOTF-based imaging spectrometer 0.4-5 um
JPL	1998	Prototype Preparation System
JSC	1998	Prototype Containment System
JPL	1999	Instrument Package Integration
JSC	1999	Prototype Environmental Control System
JPL	1999	Full-up testbed - including sample selection, acquisition, preparation, analysis, containment and preservation

BUDGETS ($M)	1991	1992	1993	1994	1995	1996	1997	1998	1999
JPL:	0.5	0.4	1.5	4.3	6.4	8.6	7.0	6.8	6.7
JSC:	0.1	0.0	0.6	1.0	1.1	1.1	1.2	1.2	1.3
Total:	0.6	0.4	2.1	5.3	7.5	9.7	8.0	8.0	8.0

SPACE SCIENCE TECHNOLOGY: IN-SITU SCIENCE

SAMPLE ACQUISITION, ANALYSIS AND PRESERVATION

OAET — MATERIALS AND STRUCTURES DIVISION

BACKGROUND

- Sample Acquisition, Analysis and Preservation (SAAP) program initiated in 1989 as an element of Project Pathfinder:
- Responsive to findings of the "Ride Report" on exploration
- Emphasized enabling technology for a Mars Rover Sample Return mission
- Multi-center program led by JPL
- Currently addressing a more general charter (still with an emphasis on Mars):

    Develop critical and significantly enhancing technologies required for in-situ analysis and possible return to earth of scientifically valuable specimens from the surface and subsurface of planets (e.g. Mars), moons and small bodies (comets and asteroids)

- $2.0 M total funding from FY 1989 to FY 1991
- No SEI funding in FY 1992 - $400 K from Materials & Structures Base R&T

SAMPLE ACQUISITION, ANALYSIS AND PRESERVATION

OAET — MATERIALS AND STRUCTURES DIVISION

OBJECTIVE

Develop component and system level technology to enable the unmanned collection, analysis and preservation of physical, chemical and mineralogical data from the surface of planetary bodies (e.g. moon, Mars)

- Site and Sample Selection
- Sample Acquisition
- Sample Analysis
- Containment and Preservation
- System Design

MISSION APPLICATIONS

- Mars Global Network
- Mars Rover Sample Return
- Comet Nucleus Sample Return
- Multiple Main Belt Asteroid Rendezvous
- Future Planetary Orbiter/Probes: Venus, Neptune, Uranus

SPACE SCIENCE TECHNOLOGY: IN-SITU SCIENCE

SAMPLE ACQUISITION, ANALYSIS AND PRESERVATION

OAET — MATERIALS AND STRUCTURES DIVISION

TECHNOLOGY NEEDS

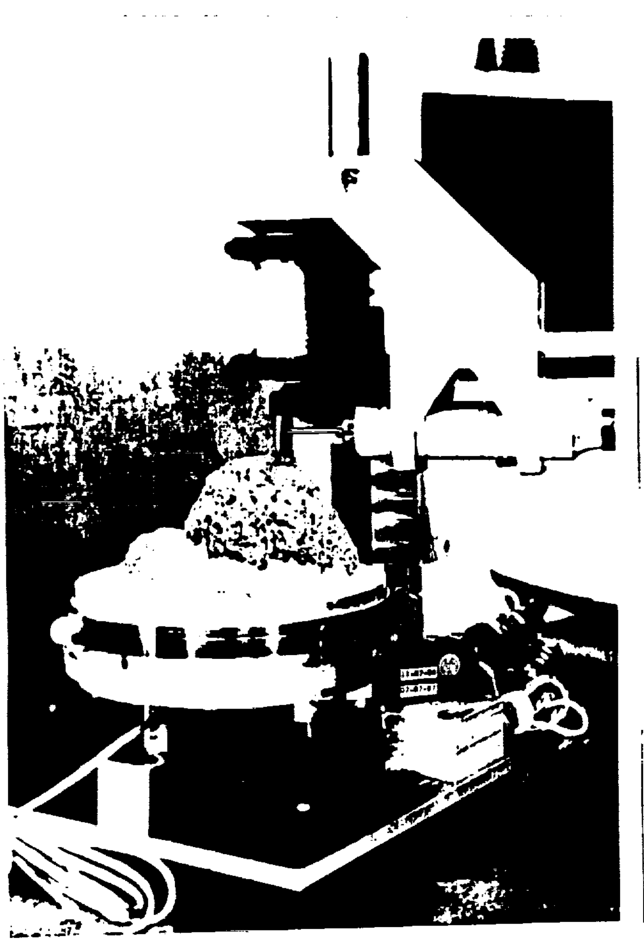
- Remote site and sample identification of scientifically valuable minerals
- Autonomous acquisition of weathered and unweathered geologic materials
  - Loose surface material
  - Rock cores (approximately 1 cm x 5 cm)
  - Deep regolith (or ice) core samples (to a depth of about 2 m to 5 m)
- On-board processing of materials for analysis and containment
- On-board analysis of acquired samples
- Packaging of samples for return to earth
- Environmental and contamination control of samples (for up to 3 years)
- System level SAAP technology integration
- *Miniature SAAP technology for "micro-rovers"- new high leverage option for robotic science missions*

TECHNOLOGY CHALLENGES

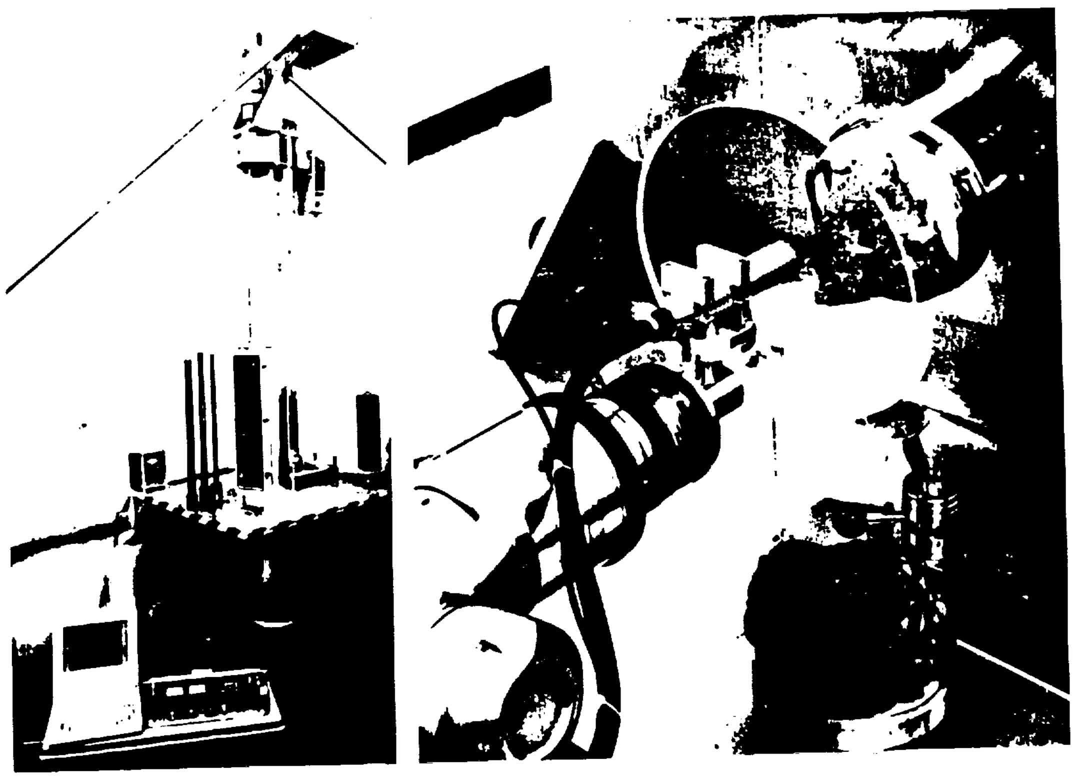
ACQUISITION

- Drilling (coring) or cutting hard material without lubricating fluid
- Removal of heat from the drilling or cutting zone
- Chip/dust removal from the drilling or cutting zone
- Drilling or cutting into material with unknown and variable properties
- Grasping loose unstructured rocks for drilling or cutting
- Securing and stabilizing the drill or saw (to minimize requirements imposed on a rover or lander)
    - Minimal forces to support the drill or saw while coring
    - Minimal disturbances transmitted from the drill or saw
- Light weight, low power and low drilling and cutting forces

Primary challenge is to acquire fresh rock cores and deep regolith cores



SAMPLE ACQUISITION, ANALYSIS AND PRESERVATION



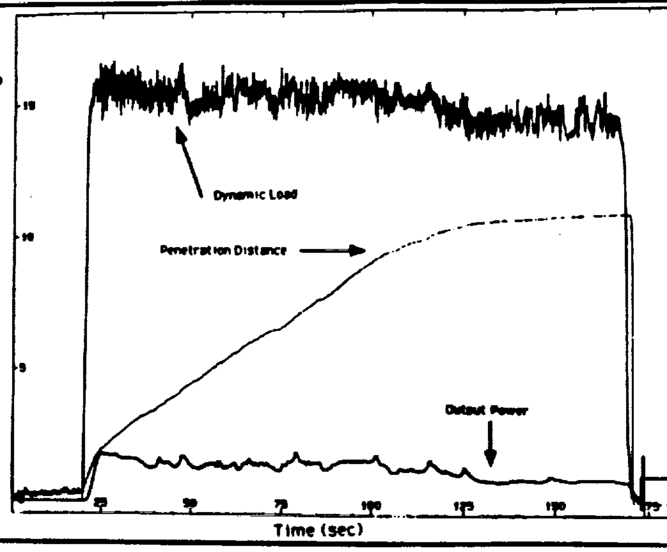
AUTONOMOUS CORING

PROJECT PATHFINDER

SAMPLE ACQUISITION, ANALYSIS AND PRESERVATION

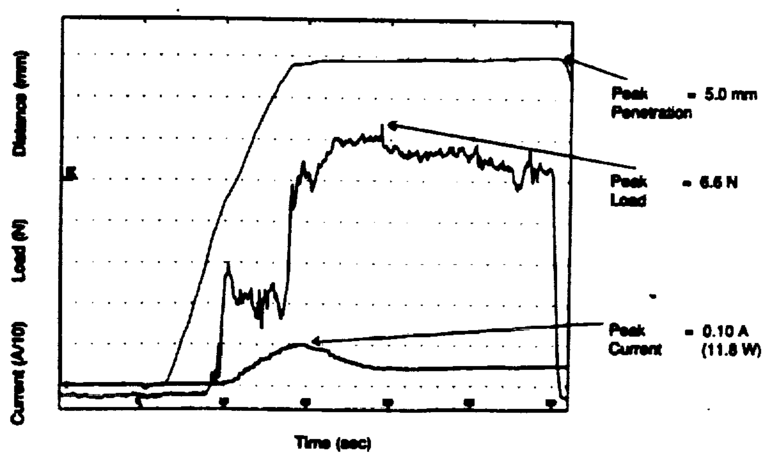
Material: Gabbro
(30,000 psi compressive strength)
Core Drill: Abrasive Technologies
0.7 cm dia. 40 mesh diamond
Applied Thrust Load
1.5 kilograms
No-load Rotational Speed
12,000 RPM

Vertical Axis Units:
Power - Watts x 10
Distance - mm
Load - grams x 100



DRILLING DATA SAMPLE

Tholeiitic Basalt Sawing Experiment



SURFACE SAMPLE ACQUISITION

TECHNOLOGY CHALLENGES

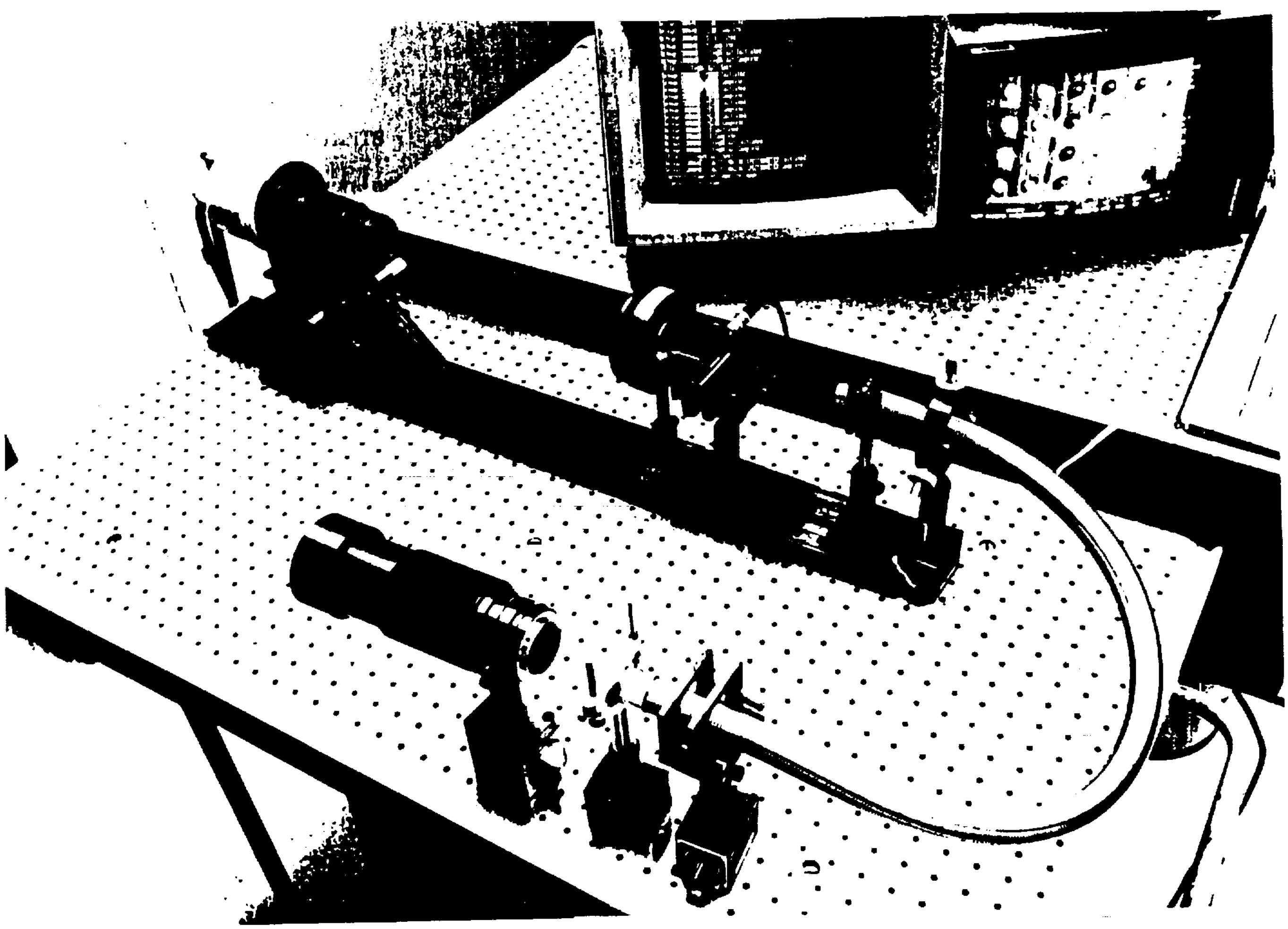
SITE and SAMPLE SELECTION

OPTICAL

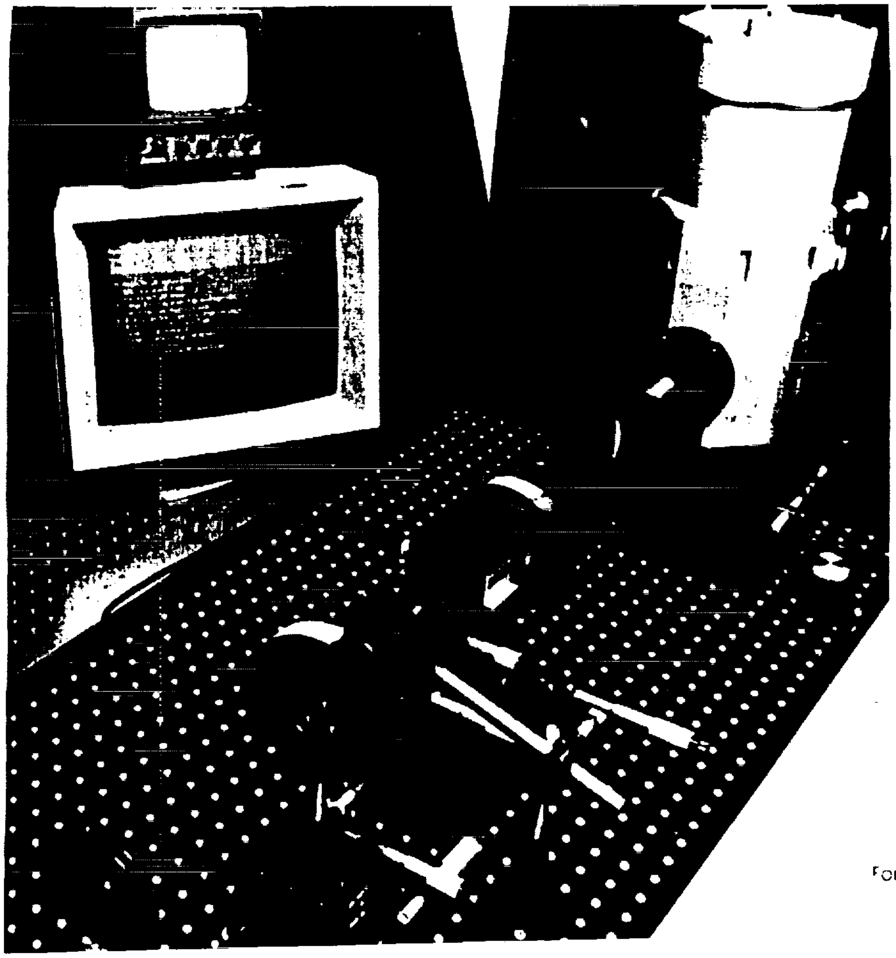
- Achieving broadband sampling spectrum in a compact instrument (from about 0.4 μm to more than 5.0 μm)
- Identifying mineral content and sample shape/size at a distance from strategically selected spectral data
- Identifying interesting geologic features at a distance incorporating optical textural data (e.g. sedimentary striations)
- Operating in highly varied lighting condition (e.g. low light, shadows, glare)
- Compensating for dust covering on scanned samples

PHYSICAL

- Non-destructive determination of solid material properties (e.g. hard, soft, brittle, monolithic, conglomerate, agglomerate, hollow)
- Identifying subsurface features and samples (e.g. near surface lithosphere material, meteorites, cavities)



1.2-2.5 MICRON AOTF IMAGING SPECTROMETER BREADBOARD



HgCdTe detector array in liquid nitrogen dewar

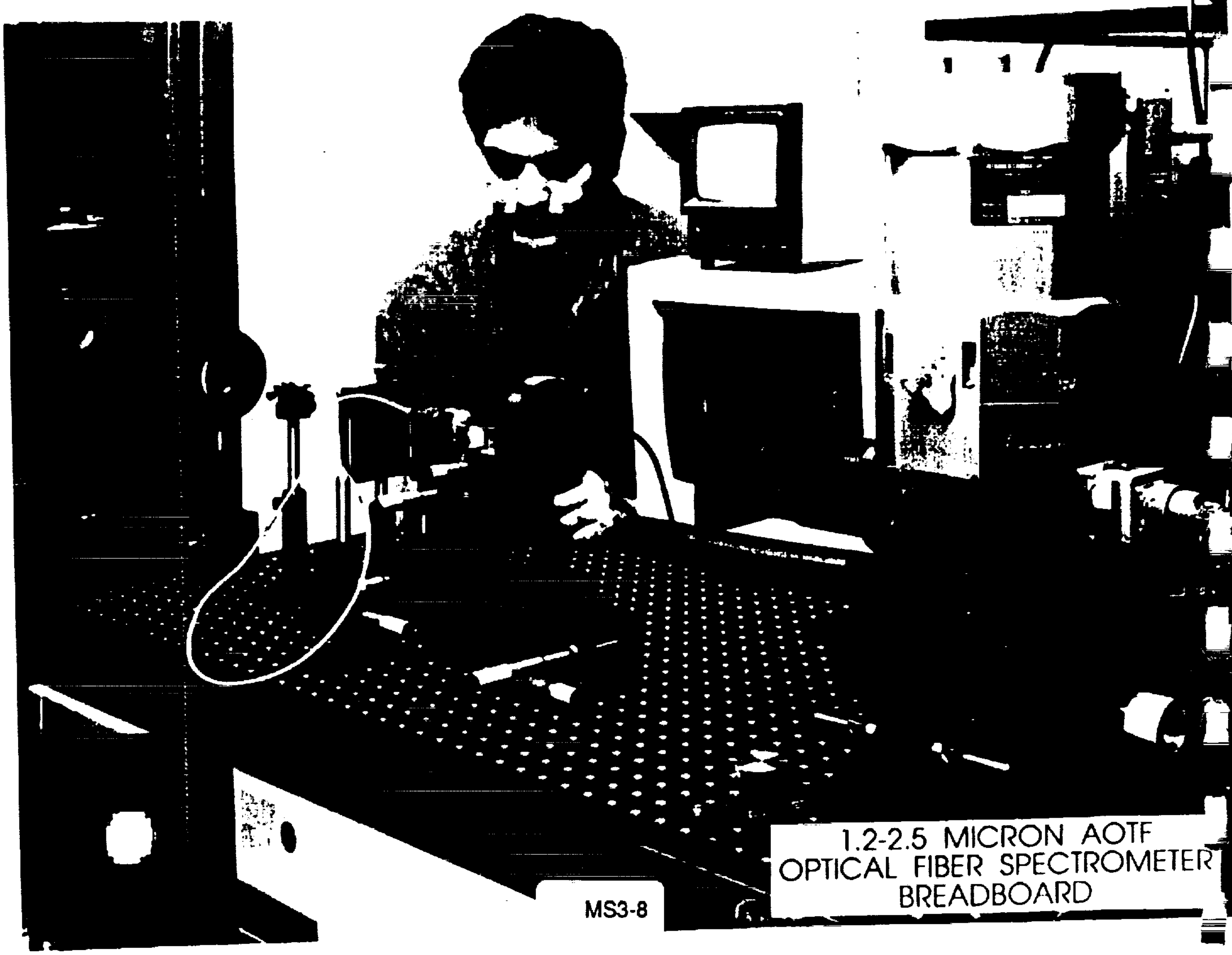
Imaging lens

Field lens

AOTF

Iris

Foreoptics



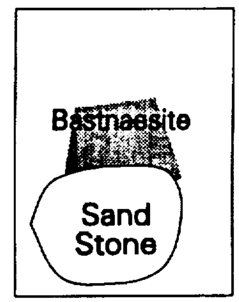
1.2-2.5 MICRON AOTF OPTICAL FIBER SPECTROMETER BREADBOARD

INFRARED AOTF IMAGES OF Bastnaesite and Sand Stone

Illustration

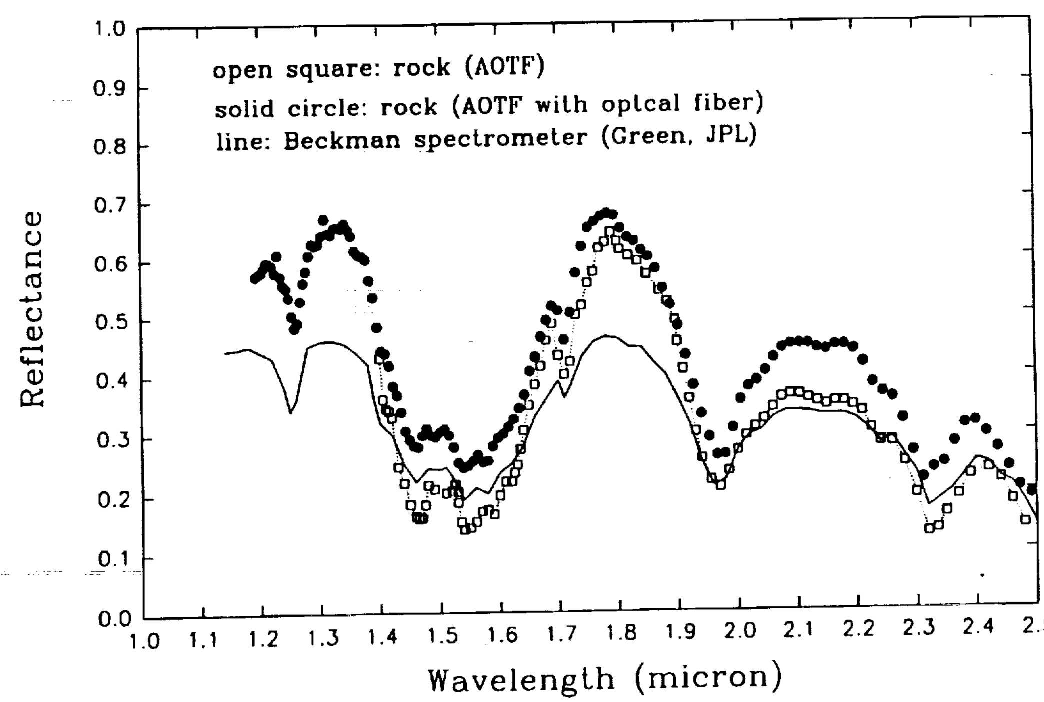
2.2 micron

2.3 micron



Bastnaesite has an absorption peak at 2.3 micron. Sand rock does not.

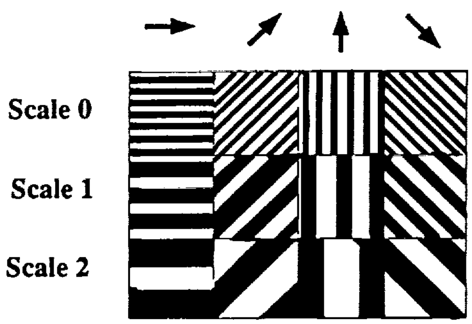
Reflection Spectra of Bastneasite Rock

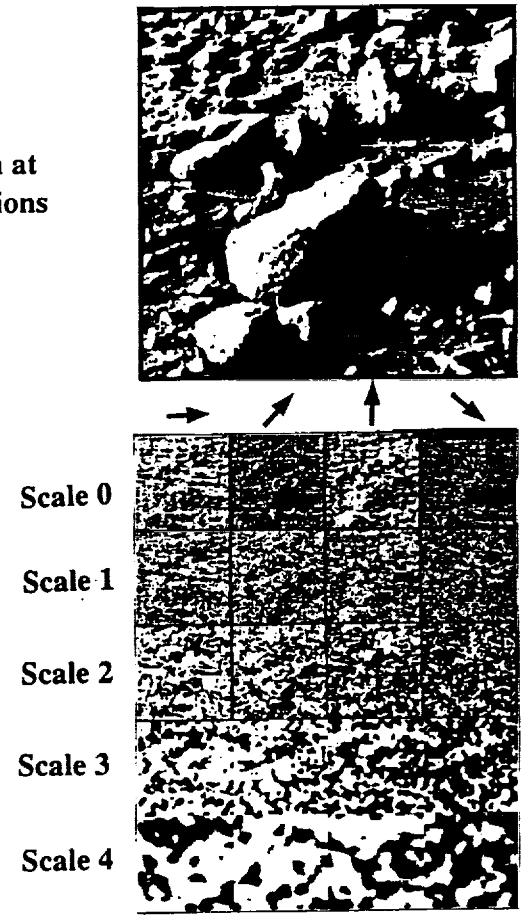


Texture Analysis

Extracting texture information at five scales and in four orientations

Orientation

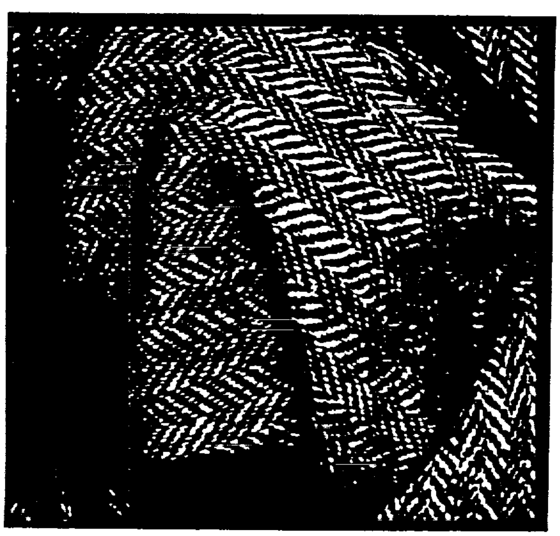


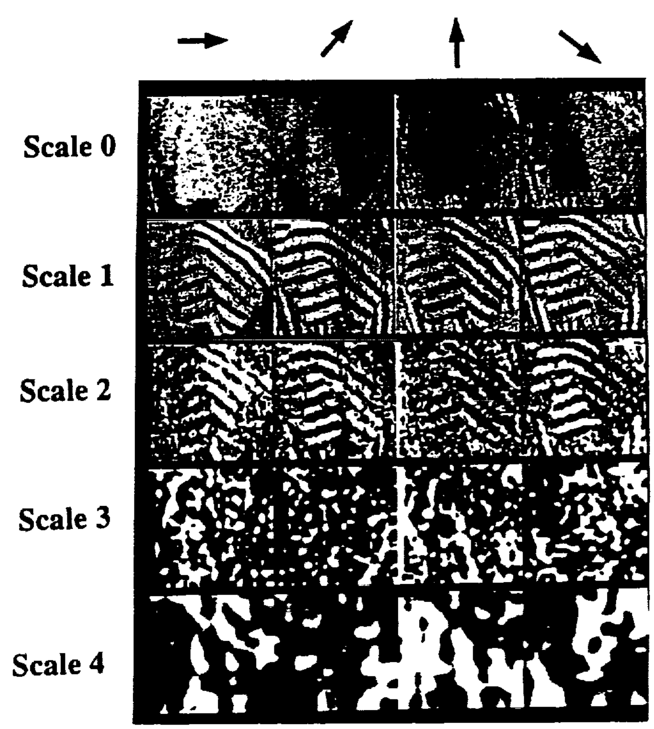


JPL Sample Acquisition, Analysis and Preservation
Autonomous Exploration

Texture Analysis

Extracting texture information at five scales and in four orientations





JPL Sample Acquisition, Analysis and Preservation
Autonomous Exploration

SPACE SCIENCE TECHNOLOGY: IN-SITU SCIENCE

SAMPLE ACQUISITION, ANALYSIS AND PRESERVATION

OAET — MATERIALS AND STRUCTURES DIVISION

TECHNOLOGY CHALLENGES

SAMPLE ANALYSIS

- Sub-sampling and preparation for presentation to instruments
- Instrument configuration and interaction for comprehensive non-conflicting analysis and sample material movement
- Prevention of sample-to-sample and inter-instrument contamination
- Reduction of analysis data to minimize transmission requirements to earth

CONTAINMENT and PRESERVATION (for sample return missions)

- Long term containment of volatile material (up to 3 years for a Mars mission)
- Low mass containment systems (current concepts can weigh more than the samples collected)

SYSTEM CONCEPT DESIGN and INTEGRATION

- Compact compatible interaction of dissimilar components
- Rugged lightweight integration
- Reliable, highly autonomous (or semi-autonomous) operation to maximize science return during operation on a remote planetary body without continuous instruction from earth

SPACE SCIENCE TECHNOLOGY: IN-SITU SCIENCE

SAMPLE ACQUISITION, ANALYSIS AND PRESERVATION

OAET — MATERIALS AND STRUCTURES DIVISION

TECHNOLOGY CHALLENGES

EXTRATERRESTRIAL ENVIRONMENT

- Temperature extremes
- Low gravity (e.g. low reaction forces to balance drilling forces)
- Lack of substantial atmosphere for convective cooling
- Dusty environments
  - Reduces container sealing effectiveness
  - Causes instrument contamination
  - Causes excess friction and wear
- Space radiation (solar flares and galactic cosmic rays)
- Unknown terrain

MINIATURIZATION

Reducing the size and weight of all SAAP technologies for very small rovers and landers - May require new concepts not currently considered for larger systems

APPROACH

- Work with mission designers and scientists to define requirements
- Select and prioritize development of critical technologies to meet mission schedule and science requirements
- Phase technology development to satisfy prioritization, mission schedule and budget
- Develop concepts to meet requirements within engineering constraints
  - SAAP is inherently a system oriented technology
  - All component concepts (e.g. coring, containment) must be operationally compatible in an overall SAAP environment
  - Overall technology development guided by reference missions though products must be adaptable to a variety of missions
  - Current reference is a Mars Rover Sample Return Mission
- Develop and test concepts analytically and experimentally to validate component level technology
- Integrate component technology into a series of successively more comprehensive testbeds to validate system level technology

CURRENT STATE OF THE ART AND PLANNED OBJECTIVES

In many cases current SAAP capability defines the state of the art

SITE and SAMPLE SELECTION

SOA: SAAP visible (0.4 µm - 0.8 µm) acousto-optical tunable filter (AOTF) based imaging spectrometer

Hierarchical classification software to identify mineralogy from spectral imagery

Image analysis software to delineate samples in an open environment

GOAL: Extend spectrometer range to near infrared (5 µm wavelength)

Integrate and automate sample delineation and identification

SAMPLE ACQUISITION

SOA: Manual lunar regolith core drill

SAAP rock coring tool operated by a stiff robotic arm

- Dry coring (no lubrication)
- Drilling rate controlled by limiting penetration force

GOAL: Low mass automatic dry coring/cutting tools for rock and regolith operable in vacuum

Automatic control to compensate for varying material properties

Minimize material heating

Automatic sample extraction after coring/cutting operation

CURRENT STATE OF THE ART AND PLANNED OBJECTIVES

SAMPLE ANALYSIS

SOA: Viking instruments:
- Gas Chromatograph/Mass Spectrometer for atomic numbers greater than 11
- X-ray fluorescence spectrometer
- Exobiology experiments

No capability to determine mineralogy

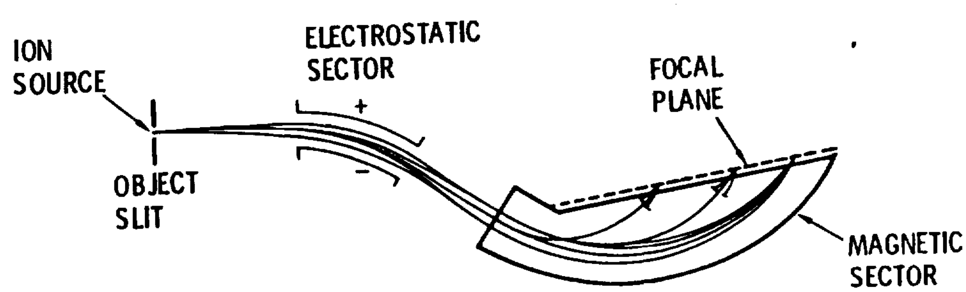
GOAL: Elemental survey: Continuous realtime GC/MS including all light elements
Organic compounds: Differential scanning calorimeter to 1000 °C
Mineralogy: Combined x-ray diffraction/fluorescence spectrometer
Low mass and low power requirements

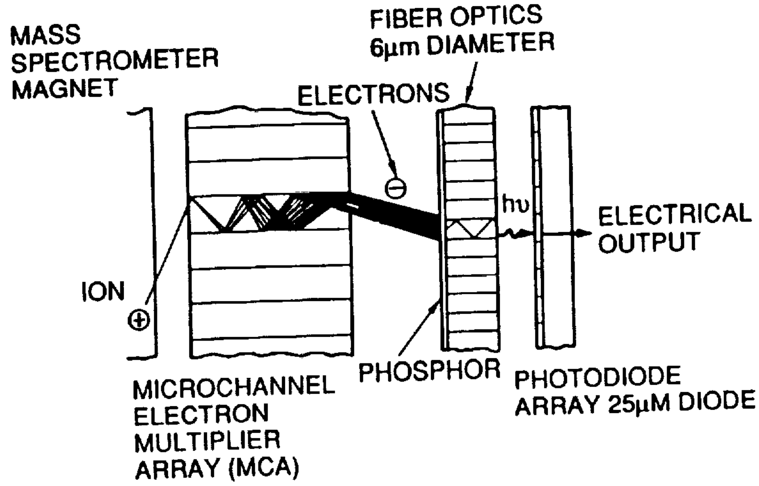
SAMPLE PROCESSING/PREPARATION

SOA: Semi-autonomous and teleoperated DOE laboratory "hot cells" for analysis of radioactive materials

GOAL: Automated grinding, crushing, cutting of samples and subsequent delivery to on-board instruments for analysis and to containers for return to earth

NON-SCANNING MASS SPECTROGRAPH





SPACE SCIENCE TECHNOLOGY: IN-SITU SCIENCE

SAMPLE ACQUISITION, ANALYSIS AND PRESERVATION

OAET — MATERIALS AND STRUCTURES DIVISION

CURRENT STATE OF THE ART AND PLANNED OBJECTIVES

SAMPLE PRESERVATION

SOA: Apollo era manually closed containers - excessive loss rate to contain volatiles over a possible 3-year sample return mission

Containment systems weighing more than the returned samples (reference 100 to 300 samples totalling about 5 kg of returned material)

Biomed freezers intended for Space Station

GOAL: Automated sealing and containment concept

Container systems for volatiles, granular and rock samples and core samples weighing less than 50% total sample weight

Pristine preservation for up to 5 years

- Less than 5% volatile loss (less than 10^{-6} cc/sec loss rate)
- Maintain temperature and pressure to prevent solid phase change
- Prevent phase change of water ice from a possible comet nucleus return mission

SPACE SCIENCE TECHNOLOGY: IN-SITU SCIENCE

SAMPLE ACQUISITION, ANALYSIS AND PRESERVATION

OAET — MATERIALS AND STRUCTURES DIVISION

OTHER DEVELOPMENT EFFORTS

DEPARTMENT OF ENERGY

The DOE is currently seeking technologies for use in hazardous waste cleanup

- Remote site evaluation and sample collection
- In-situ chemical/physical material analysis
- May consider using technology developed under SAAP

PRIORITIES AND AUGMENTATION

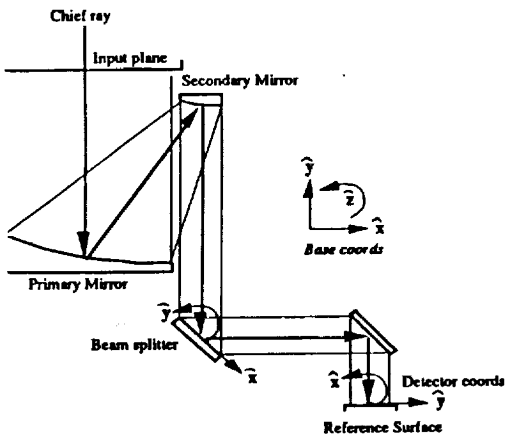
CURRENT PROGRAM: FY 1991 and FY 1992

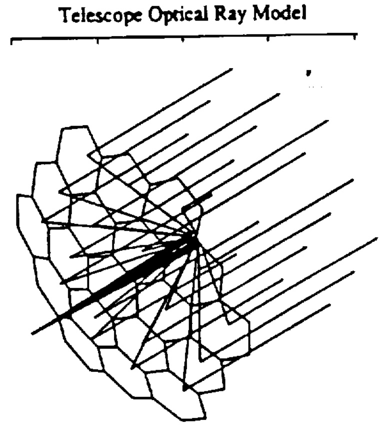
- Continue focus on Mars robotic science mission
- Emphasize most critical technology to support Mars Global Network (MGN) over Mars Rover Sample Return Mission (MRSR)
  - MGN likely to precede MRSR by about 3 years
  - Continue development of AOTF imaging spectrometer
  - Continue development of small, lightweight, reliable rock coring drill concept

FY 1993 AUGMENTATION

- Maintain priority to support readiness by FY 1996 for a Mars Global Network mission
  - Emphasis on in-situ acquisition of scientifically valuable data
  - Maintain emphasis on sample identification and rock and regolith coring
  - May not involve on-board analysis other than screening
- Restore program to develop comprehensive SAAP technologies by FY 1998 to support readiness for a MRSR mission
- Expand activities in coring, and preservation to support readiness by FY 1996 for a Comet Nucleus Sample Return mission
- Expand sample acquisition to include dust collection (e.g. comet fly-by, cosmic dust)
- Initiate new activity to develop "micro-SAAP" technology

N93-71838





TELESCOPE OPTICAL SYSTEMS PROGRAM OVERVIEW

S4-81
157514
P- 8

Murray S. Hirschbein
Richard W. Key

June 26, 1991

TELESCOPE OPTICAL SYSTEMS OVERVIEW

Many future NASA missions need advanced telescope optical systems to achieve their mission goals. Most of the optical system concepts being considered have technology requirements that are unique to NASA missions. Advanced filled aperture telescopes need lightweight mirrors, and figure control if they are segmented reflectors. A filled arm Fizeau telescope needs lightweight optics, precision deployment, and extremely stable structural materials. Space interferometers require very high precision metrology, and nanometer level structural stability. Cryogenic telescopes like SIRTF need advanced optical and structural materials that retain their dimensional and mechanical stability even at temperatures as low as 3K. Optical telescopes for extra-solar planet detection need advanced optics with very low light scattering properties. New high fidelity test beds are needed to enable comprehensive analysis of complex optical systems like those mentioned above, and for validating Lunar based observatory concepts. Undertaking a telescope technology program will provide NASA with in-house "hands-on" experience, and allow NASA to leverage significant technology developments in industry and academia.

Telescope Optical Systems is a new focused program of technology development that will shape and enable the new "telescope" missions being studied and planned by NASA. The program structure contains six major elements: Systems, Optics, Materials, Structures, Controls, and Integration & Test. The activities in each element will address key technology issues that support a wide range of user needs. The scope and pace of development will be closely coordinated with OSSA needs and plans, and will provide the basis for lunar observatories. In addition to component level technology, test beds will be developed to provide a "bridging" mechanism to advance technology to the systems level. Development of high fidelity test bed demonstrations may serve as an alternative to complex and costly space flight experiments. For example, the development of segmented reflector test bed would extend PSR program objectives, and provide for the demonstration of complete segmented reflector system appropriate for space application. Like other focused programs, this one will pick up and further develop advanced concepts and technologies from base R&T programs. The program is also designed to coordinate with and leverage other programs and developments in government, industry, and academia.

INTRODUCTION

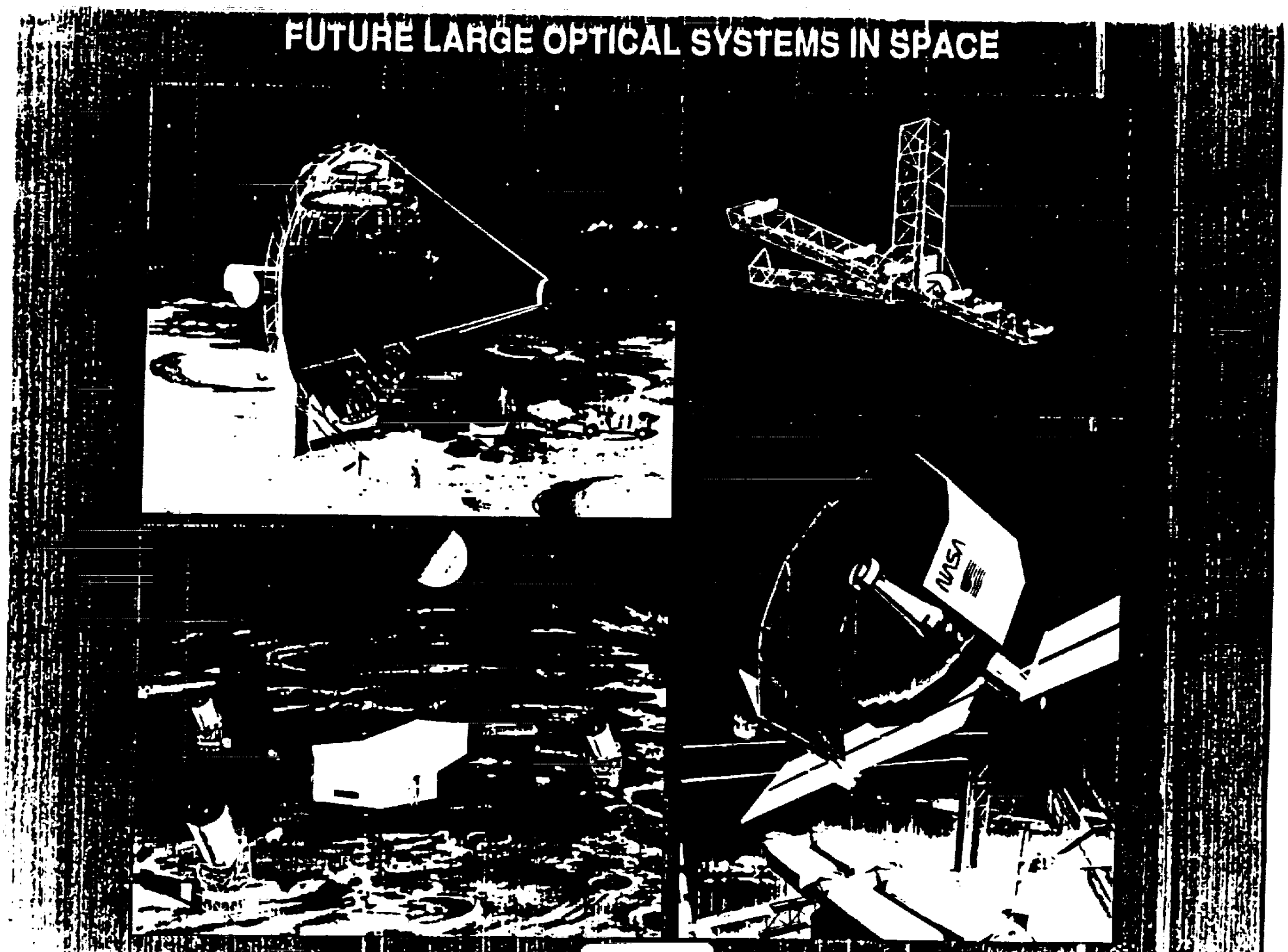
- NASA IS STUDYING AND PLANNING NUMEROUS FUTURE SPACE AND LUNAR MISSIONS WHICH EMPLOY TELESCOPE OPTICAL SYSTEMS

- OSSA EXPECTS OAET TO DEVELOP TELESCOPE OPTICAL SYSTEMS TECHNOLOGIES FOR THESE FUTURE MISSIONS

- THE TELESCOPE OPTICAL SYSTEMS PROGRAM WILL DEVELOP COMPONENT AND SYSTEMS LEVEL TECHNOLOGIES IN OPTICS, MATERIALS, STRUCTURES, AND CONTROLS

- PROGRAM ACTIVITIES WILL EMPHASIZE SYSTEMS LEVEL CONCEPT ANALYSIS, DEVELOPMENT, AND DEMONSTRATION

- THE TELESCOPE OPTICAL SYSTEMS PROGRAM WILL ADVANCE THE TECHNOLOGY MATURITY TO A LEVEL OF READINESS APPROPRIATE FOR MISSION BASELINE DESIGN



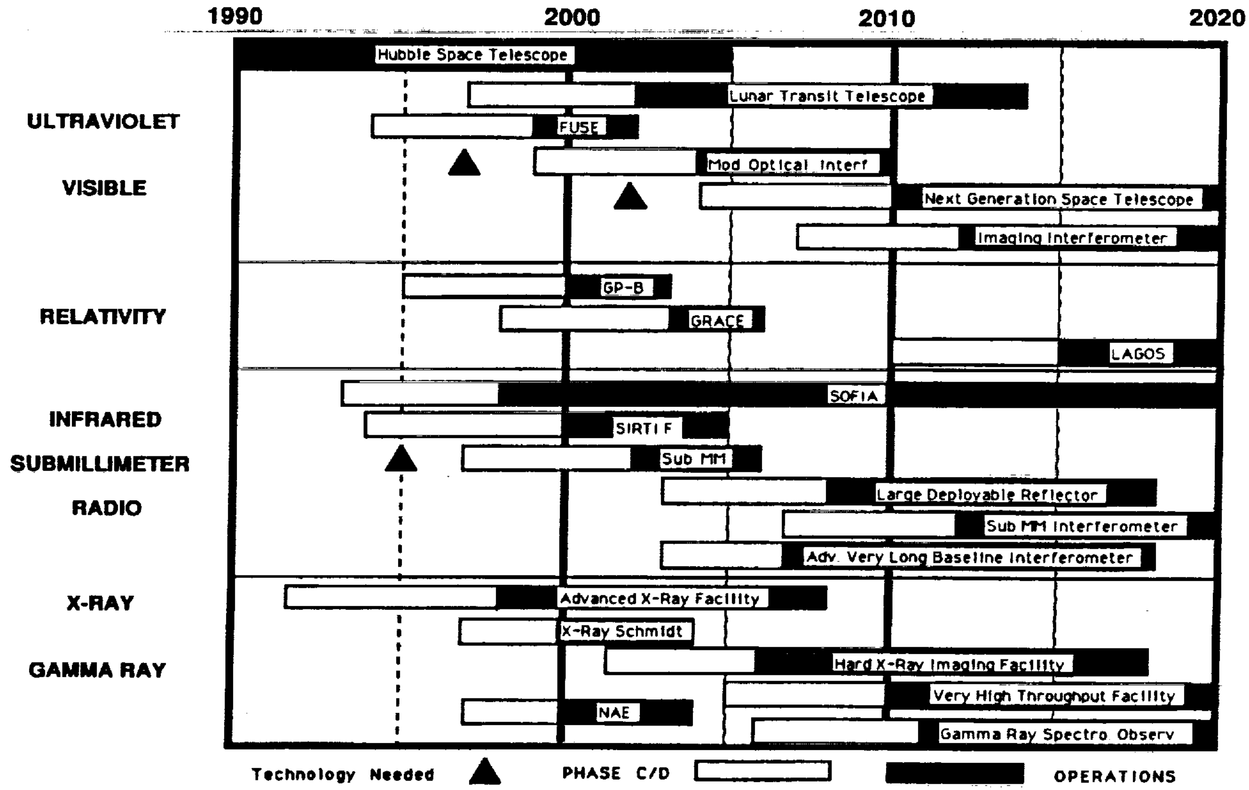
OAET, OSSA AND SCIENCE COMMUNITY INPUTS TO PROGRAM PLAN

- EXPLORATION TECHNOLOGY PROGRAM PLAN: LUNAR AND MARS SCIENCE TECHNOLOGY SUMMARY, NOVEMBER 16, 1990
- PRECISION SEGMENTED REFLECTOR PROGRAM LONG RANGE PLAN, NOVEMBER, 1990
- INDUSTRY TOURS, FEBRUARY-APRIL 1991
- LARGE FILLED APERTURE TELESCOPES IN SPACE WORKSHOP, MARCH 4-5, 1991
- ASTROTECH 21 OPTICS TECHNOLOGY WORKSHOP, MARCH 6-8, 1991
- THE DECADE OF DISCOVERY IN ASTRONOMY AND ASTROPHYSICS, (BAHCALL REPORT), MARCH 18, 1991
- EXPLORATION TECHNOLOGY PLANNING UPDATE, MARCH 19, 1991
- TOWARDS OTHER PLANETARY SYSTEMS (TOPS) TECHNOLOGY NEEDS IDENTIFICATION WORKSHOP, APRIL 22-24, 1991
- OSSA TECHNOLOGY NEEDS (S. HARTMAN), MARCH 21, 1991
- TECHNOLOGIES FOR ADVANCED PLANETARY INSTRUMENTS WORKSHOP, MAY 8-10, 1991

TELESCOPE MISSIONS

GENERAL ASTRONOMY
RADIO
SUBMILLIMETER
INFRARED
ULTRA VIOLET
X-RAY
RELATIVISTIC GRAVATION
PLANETARY SCIENCE

ASTROPHYSICS MISSION MODEL



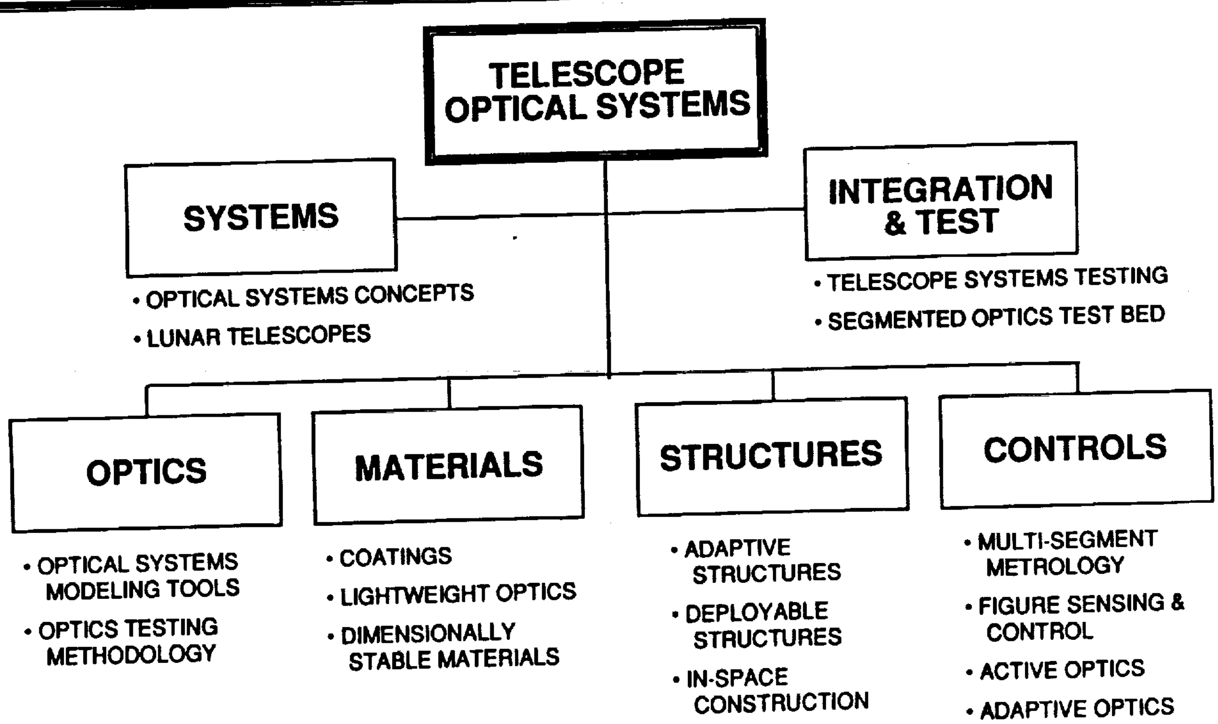
MISSION AND SCIENCE DRIVEN TELESCOPE ISSUES

- OBSERVATIONAL BANDWIDTHS (x-ray, UV/VIS, IR, submillimeter, RF)
- OPERATING TEMPERATURES (warm, passively cooled, cryogen cooled)
- RESOLUTION, CONTRAST AND COLLECTING POWER
- FIELD OF VIEW
- APERTURE SIZE AND F#
- FILLED vs. UNFILLED APERTURE
- SEGMENTED vs. MONOLITHIC REFLECTORS
- DEPLOYABLE vs. ERECTABLE
- PASSIVE vs. ACTIVE CONTROL (mirror and structure)
- SPACE OPTICAL SYSTEM CONCEPT EVALUATION TOOLS (MODELS)
- ORBITING vs. LUNAR BASED
- HUMAN OR ROBOTIC SERVICEABILITY
- LAUNCH SYSTEMS
- COST

TELESCOPE OPTICAL SYSTEMS TECHNOLOGY NEEDS SUMMARY

- LIGHTWEIGHT HIGH PRECISION REFLECTOR SYSTEMS
- SPACE DURABLE MATERIALS AND COATINGS
- CONSTRUCTABLE & DEPLOYABLE SPACE STRUCTURES
- FIGURE SENSING & CONTROL SYSTEMS APPROPRIATE FOR SPACE APPLICATIONS
- TELESCOPE OPTICAL SYSTEMS DESIGN, ANALYSIS, AND TEST TOOLS
- INTEGRATED TELESCOPE OPTICAL SYSTEMS TEST BEDS

TELESCOPE OPTICAL SYSTEMS PROGRAM STRUCTURE



TELESCOPE OPTICAL SYSTEMS PROGRAM GOALS

- PROVIDE THE ENABLING OPTICAL SYSTEMS TECHNOLOGIES FOR NASA SPACE AND LUNAR MISSIONS
- ADDRESS KEY TECHNOLOGY ISSUES IDENTIFIED BY MULTIPLE USERS
- BALANCE THE PRIORITY AND PACE OF TECHNOLOGY DEVELOPMENT TO MATCH SCIENCE MISSION SCHEDULES
- STRENGTHEN NASA PARTNERSHIPS WITH INDUSTRY AND ACADEMIA
- COORDINATE PLANS AND OBJECTIVES WITH BASE R&T DEVELOPMENTS AND OTHER TECHNOLOGY PROGRAMS
- USE TEST BEDS AS A "BRIDGING" MECHANISM TO ADVANCE THE TECHNOLOGY FROM THE COMPONENT TO THE SYSTEM LEVEL
- DEMONSTRATE TECHNOLOGY READINESS VIA HIGH FIDELITY TEST BEDS

TELESCOPE OPTICAL SYSTEMS TECHNOLOGY CHALLENGES

- MATERIALS, DESIGNS AND FABRICATION TECHNIQUES FOR LARGE , STABLE, HIGH PRECISION OPTICAL SYSTEMS
- MATERIALS, DESIGNS, FABRICATION TECHNIQUES, AND DEPLOYMENT STRATEGIES FOR LARGE, STABLE, LINEAR, HIGH PRECISION STRUCTURES
- CONTROL ALGORITHMS AND HARDWARE FOR HIGH PRECISION, HIGH BANDWIDTH FIGURE CONTROL SYSTEMS
- INTEGRATED SYSTEM MODELLING (SCIENCE, OPTICAL, STRUCTURAL, CONTROL, AND ENVIRONMENTAL)
- GROUND BASED TEST METHODOLOGIES FOR OPTICAL, STRUCTURAL AND CONTROL SYSTEMS AT OR NEAR FULL SCALE IN SIMULATED USE ENVIRONMENT

TELESCOPE OPTICAL SYSTEMS STATE-OF-THE-ART ASSESSMENT

- HUBBLE SPACE TELESCOPE (HST)
  - 2.4 METER MONOLITHIC ULE GLASS MIRROR (185 KG/SQ-M, 2 YR. FAB., 12Å RMS)
  - 10^{-6} DIMENSIONALLY STABLE STRUCTURE
- ADVANCED X-RAY ASTROPHYSICS FACILITY (AXAF) TELESCOPE
  - 20 PIECE 1 METER CLASS GRAZING INCIDENCE X-RAY OPTICS (5A° RMS SURFACE)
  - 10^{-6} DIMENSIONALLY STABLE STRUCTURE
- LARGE APERTURE MIRROR PROGRAM (LAMP)
  - 4 METER SEGMENTED (7 OF 1.3 METER DEFORMABLE MIRRORS, 300 KG/SQ-M)
  - MONOCHROMATIC FIGURE SENSING & CONTROL OF DEFORMABLE OPTICS
- PRECISION SEGMENTED REFLECTOR (PSR) PROGRAM
  - 4 METER SEGMENTED (1 METER GRAPHITE/EPOXY PANELS, 15 KG/SQ-M)
  - SCIENCE SENSOR FOCAL PLANE IMAGE SHARPENING FIGURE INITIALIZATION
  - OPTICAL TRUSS 6 DEGREE OF FREEDOM PANEL FIGURE SENSING & CONTROL
- KECK TELESCOPE
  - 10 METER SEGMENTED (36 OF 1.8 METER GLASS PANELS, 200 KG/SQ-M)
  - SPECIAL SHACK-HARTMAN ALIGNMENT CAMERA FIGURE INITIALIZATION
  - EDGE SENSOR 3 DEGREE OF FREEDOM PANEL RELATIVE FIGURE CONTROL
  - GROUND BASED HUMAN SERVICEABILITY

TELESCOPE OPTICAL SYSTEMS TECHNOLOGY PERFORMANCE OBJECTIVES

- LIGHTWEIGHT HIGH PRECISION REFLECTOR SYSTEMS
  - 15 KG/SQ. M, 1NM SURFACE, 6 TO 8 METER INTEGRATED OPTICS-STRUCTURES-CONTROL
- SPACE DURABLE MATERIALS AND COATINGS
  - 100K TEMPERATURE, 10^{9} RAD, AO+VUV RESISTANT, 10^{-8} DIMENSIONAL STABILITY
- CONSTRUCTABLE & DEPLOYABLE SPACE STRUCTURES
  - HYBRID SINGLE FOLD, MICRON DEPLOYMENT PRECISION, 10^{-7} DIMENSIONAL STABILITY
- FIGURE SENSING & CONTROL FOR SEGMENTED OPTICS
  - 1MINUTE, 1NM FIGURE INITIALIZATION, LOW POWER 1NM FIGURE MAINTENANCE, INTEGRATED CONTROL-STRUCTURES-OPTICS
- TELESCOPE OPTICAL SYSTEMS DESIGN, ANALYSIS, AND TEST TOOLS
  - EASY TO USE, FAST, OPTICS-STRUCTURES-CONTROL-THERMAL SYSTEM OPTIMIZATION
- INTEGRATED OPTICAL SYSTEMS TEST BEDS
  - INTEGRATED SCIENCE SENSING-OPTICS-STRUCTURES-CONTROL-THERMAL VALIDATION
  - CRYOGENIC OPERATING ENVIRONMENT

TELESCOPE OPTICAL SYSTEMS
PROGRAM TARGET MILESTONES

FY92
- Complete Characterization of 100K Temperature Materials
- Composite Panel Optical Test Capability to 130K Temperature

FY93
- 3μm, 3m Radius of Curvature, 100K, 1m Size Parabolic Panel
- Demonstrate Panel Coating (Optics Performance & Protection)

FY94
- Multi-Panel Diffraction Modeling Tool Developed
- Integrated Figure Control Demonstration for 4m Class Reflector

FY95
- 1μm, 7.5m Radius of Curvature, 100K, 2m Size Parabolic Panel
- 100 μm Deployable Structure Demonstration

FY96
- 1M Class Optical Coronograph Test Bed Demonstration
- Specification of Materials for Lightweight Submicron Mirrors

FY97
- Lightweight, Submicron, 100K, 2m Parabolic Mirror Segments
- Submicron Figure Control Demonstration

($K)	FY 93	FY 94	FY 95	FY 96	FY 97
CURRENT	0	0	0	0	0
PLANNED	8100	13100	15250	18500	21250
3X	7900	9000	11100	11700	14400

TELESCOPE OPTICAL SYSTEMS
SUMMARY

- NASA NEEDS OPTICAL SYSTEMS TECHNOLOGY
- PROGRAM ACTIVITIES WILL EMPHASIZE SYSTEMS LEVEL CONCEPT ANALYSIS, SYSTEMS DEVELOPMENT AND DEMONSTRATION
- INDUSTRIAL AND ACADEMIC PARTNERSHIPS ARE NEEDED
- GROUND TEST BEDS WILL BE DEVELOPED TO VALIDATE SYSTEMS DESIGNS FOR SPACE AND LUNAR INSTRUMENT CONCEPTS
- HIGH FIDELITY TEST BED DEMONSTRATIONS MAY BE AN ALTERNATIVE TO COSTLY TECHNOLOGY FLIGHT EXPERIMENTS

Discipline Program Review

SSTAC ARTS Materials and Structures

N93-71839

JPL Control-Structure Interaction Technology

Micro-Precision CSI

S5-81
157515
p 18

Robert A. Laskin

JPL CSI Task Manager

26 June 1991

NASA CSI Program Goals

- **CONTROLLED STRUCTURE PERFORMANCE ENHANCEMENT**
  - **Tenfolds of Steady State Performance Improvement**
  - **Halved Dynamic Response to Impulsive Disturbances**

- **CONTROLLED STRUCTURE UNIFIED METHODS FOR DESIGN/ANALYSIS**
  - **Integrated Synthesis of Control and Structure Subsystems**
  - **Prediction of Flight Responses, To 10% Accuracy**

- **GROUND VALIDATION METHODS FOR CSI FLIGHT SYSTEMS**

JPL Control Structure Interaction Technology Program

NASA CSI Charter To Centers

Develop Technology to: 1) Control Structural Dynamics
2) Control Pointing in Spite Of Structural Dynamics

Langley Research Center

- Multi-Payload Space Platforms
  - Advanced Space Station
  - Advanced EOS

Jet Propulsion Laboratory

- Precision Controlled Structures
  - Large Optical Systems
  - Large Precision Antennas

Marshall Space Flight Center

- ACES CSI Ground Test Bed
- CASES Flight Experiment

Micro-Dynamic Component Tests

- Performance Linearity
  - Structural & Optical Joints
  - Viscous & Viscoelastic Dampers
- Thermal / Structural Creak
  - Joints & Composite Mat'ls

System Level Ground Testing

- Static Misalignment Correction
- Thermal Distortion Correction
- Impedance Detuning
- Active/Passive Motion Isolation
- Active/Passive Motion Reduction
- Active Motion Compensation

Control/Structure System Methods

- Requirements Development
- New Design/Analysis Tools
- New Integrated Modeling Tools
- Advanced Optimization Tools
- Ground/Flight Technology Demos.

JPL Control-Structure Interaction Organization

Control-Structure Interaction
R. A. Laskin Task Mgr
J. L. Fanson Deputy Tsk Mgr.

Management Review Team
G.Burdick, R. Barlow, D.Hess,
R. Stanton, R.Key, C.Lifer,
B.McGlinchey, H.Otake, MJ Mahoney

Technical Advisors
M. Shao, F. Tolivar,
B. Wada, W. Layman

Systems & Concepts
R. Laskin
Lead Technologist

- Mission Definitions
- CSI Systems Synthesis
- Coordination of JPL, LaRC, MSFC

Analysis & Design
M. Milman
Lead Technologist

- Modeling Tools
- Optimization Tools
- Simulation Tools
- Anal/Dsgn Support

Test Beds & Active Structures
J. Fanson
Lead Technologist

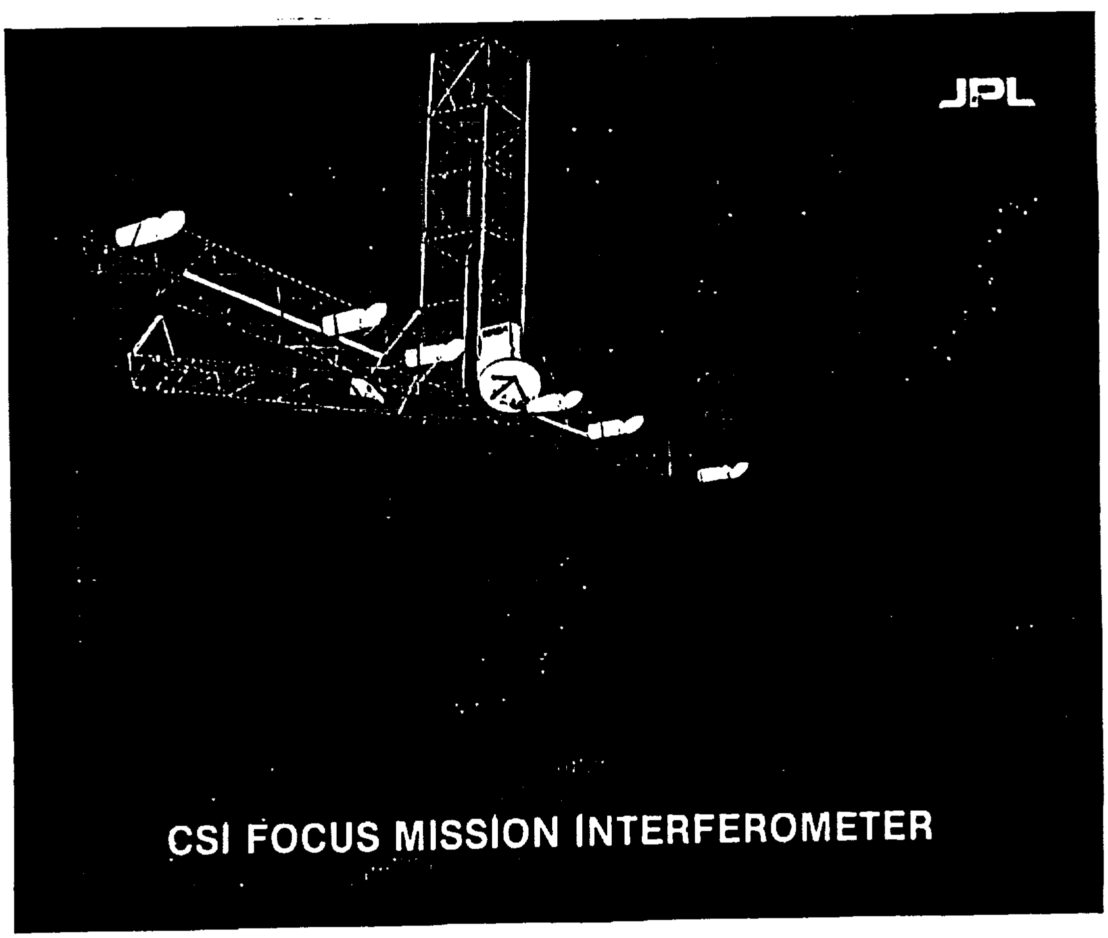
- Active Structure Devel.
- Micro-dynamics Eval.
- Test Facilities
- CSI System Validation

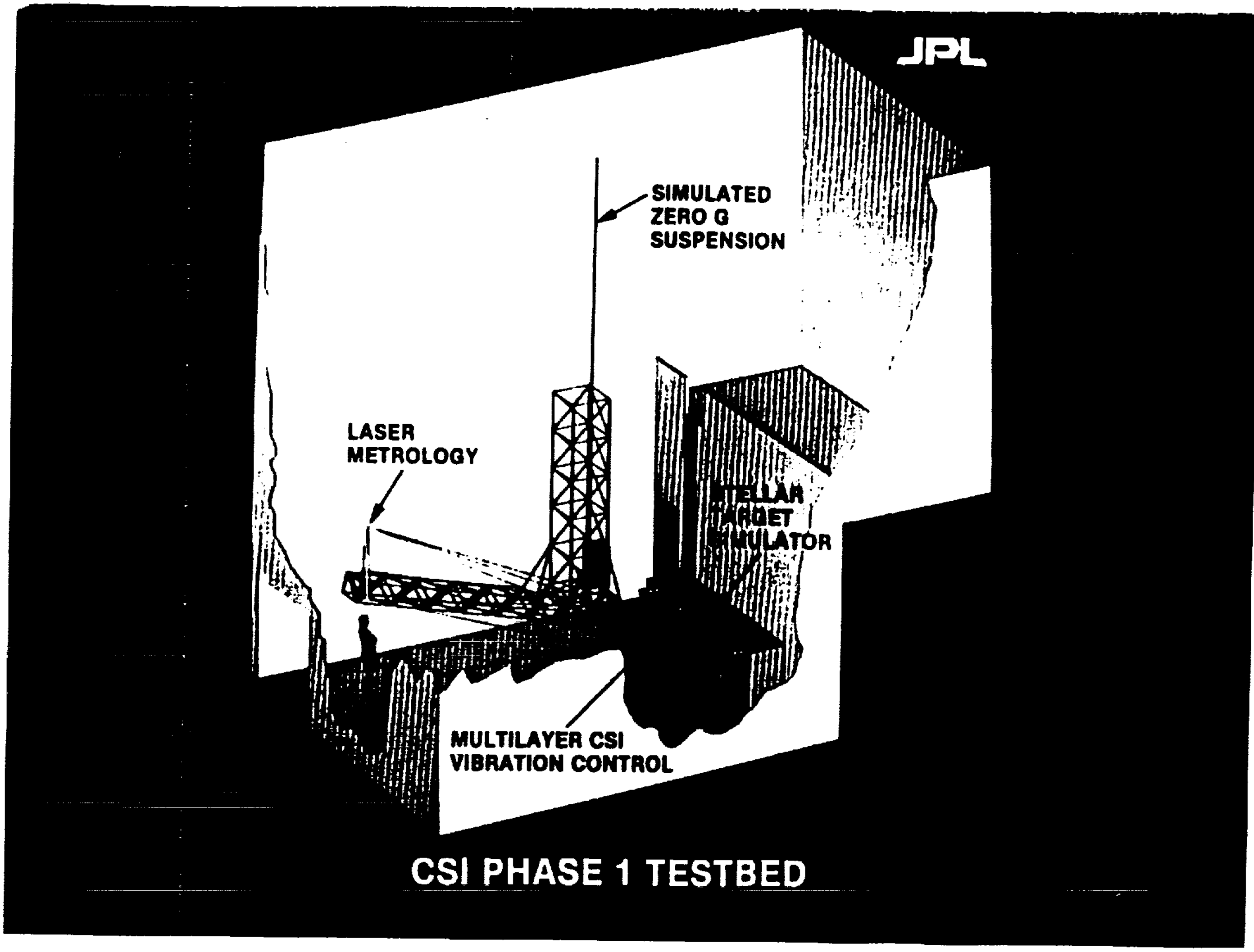
Flight Experiments
R. Laskin (acting)
Lead Technologist

- Define CSI Flt. Needs
- Find Opportunities
- Propose Experiments
- Coord. with LaRC, MSFC, HQ

Guest Investigator Prgrm
R. Laskin (acting)
Lead Technologist

- Define JPL Test Bed Opportunities to G.I.'s
- NRA Support
- Interface: JPL Test Bed Investigators





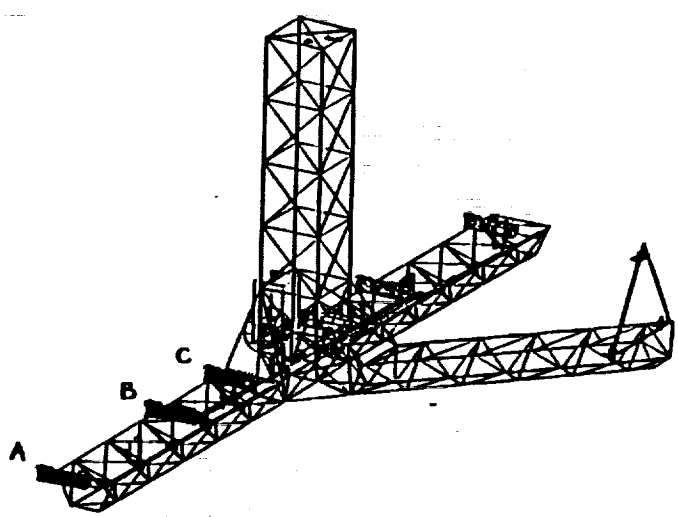
INTEGRATED DESIGN PROBLEM OVERVIEW

GOALS

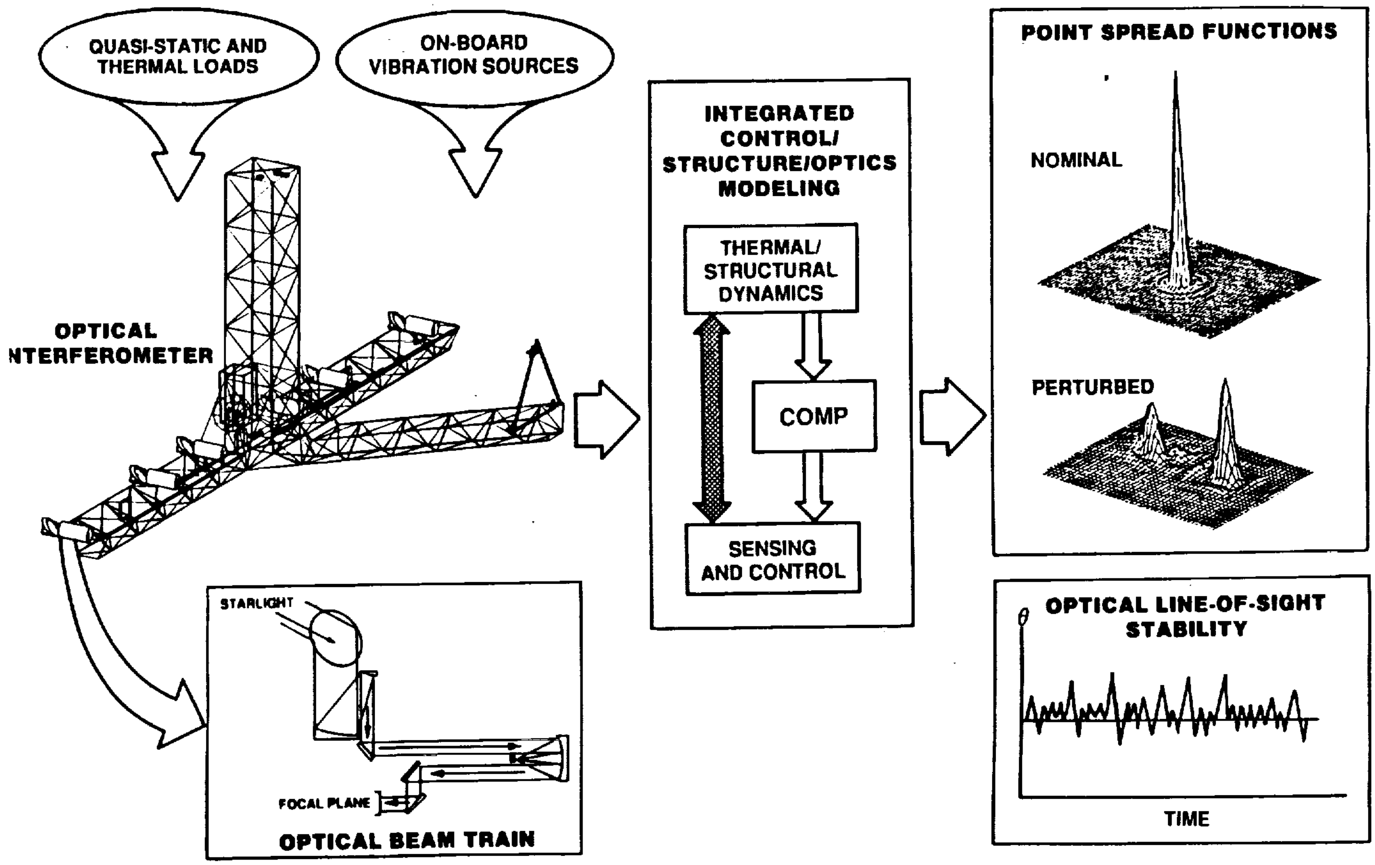
- –Minimize wavefront/LOS error
- –Minimize total system mass
- –Minimize power consumption
- –Others

DESIGN VARIABLES

- –Structure parameters
- –Control gains
- –Optical design variables



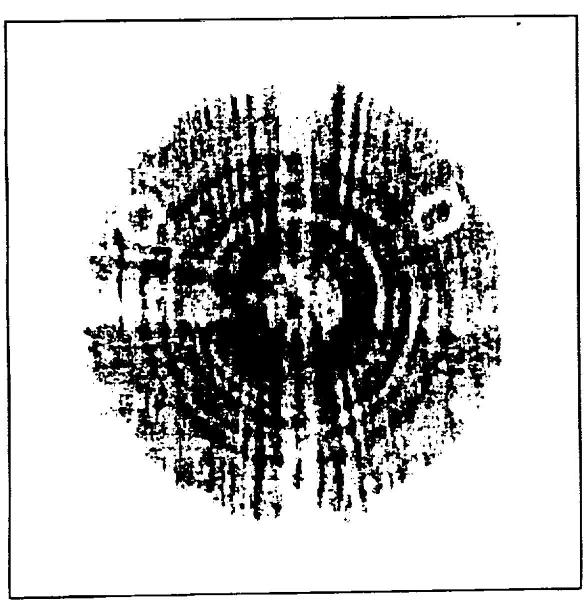
JPL CONTROLLED OPTICS MODELING PACKAGE (COMP)



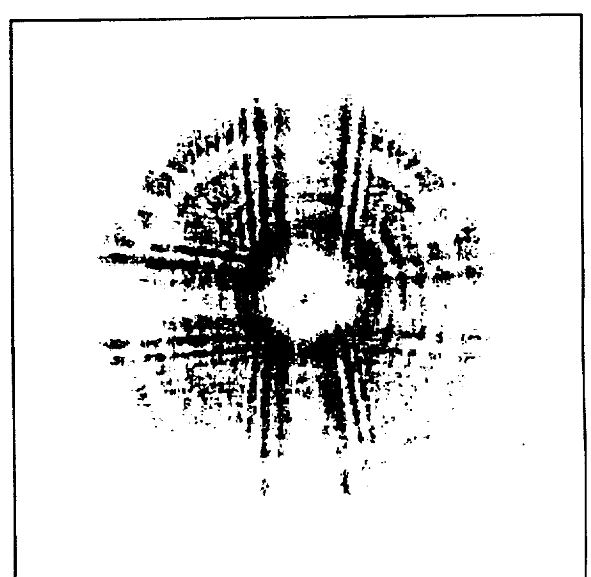
JPL

COMP – CONTROLLED OPTICS MODELING PACKAGE

HST PRESCRIPTION RETRIEVAL



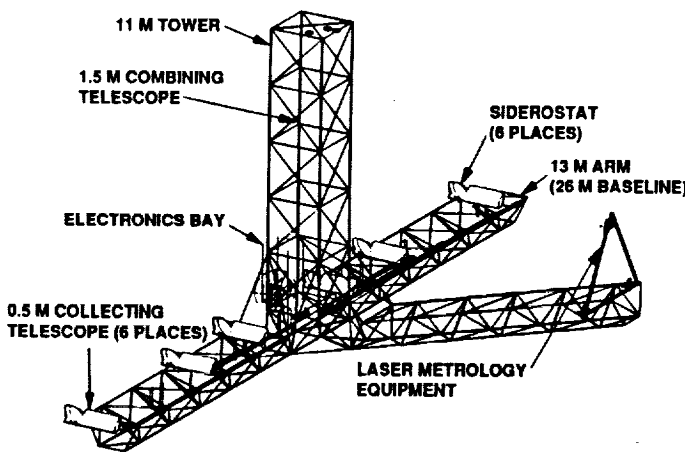
HST IMAGE DATA



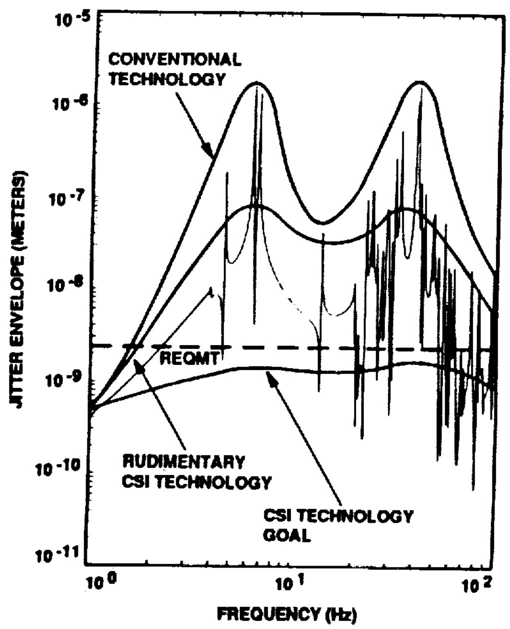
COMP SIMULATION

JPL CSI VIBRATION CONTROL REQUIREMENTS
(FOCUS MISSION INTERFEROMETER)

FMI CONFIGURATION

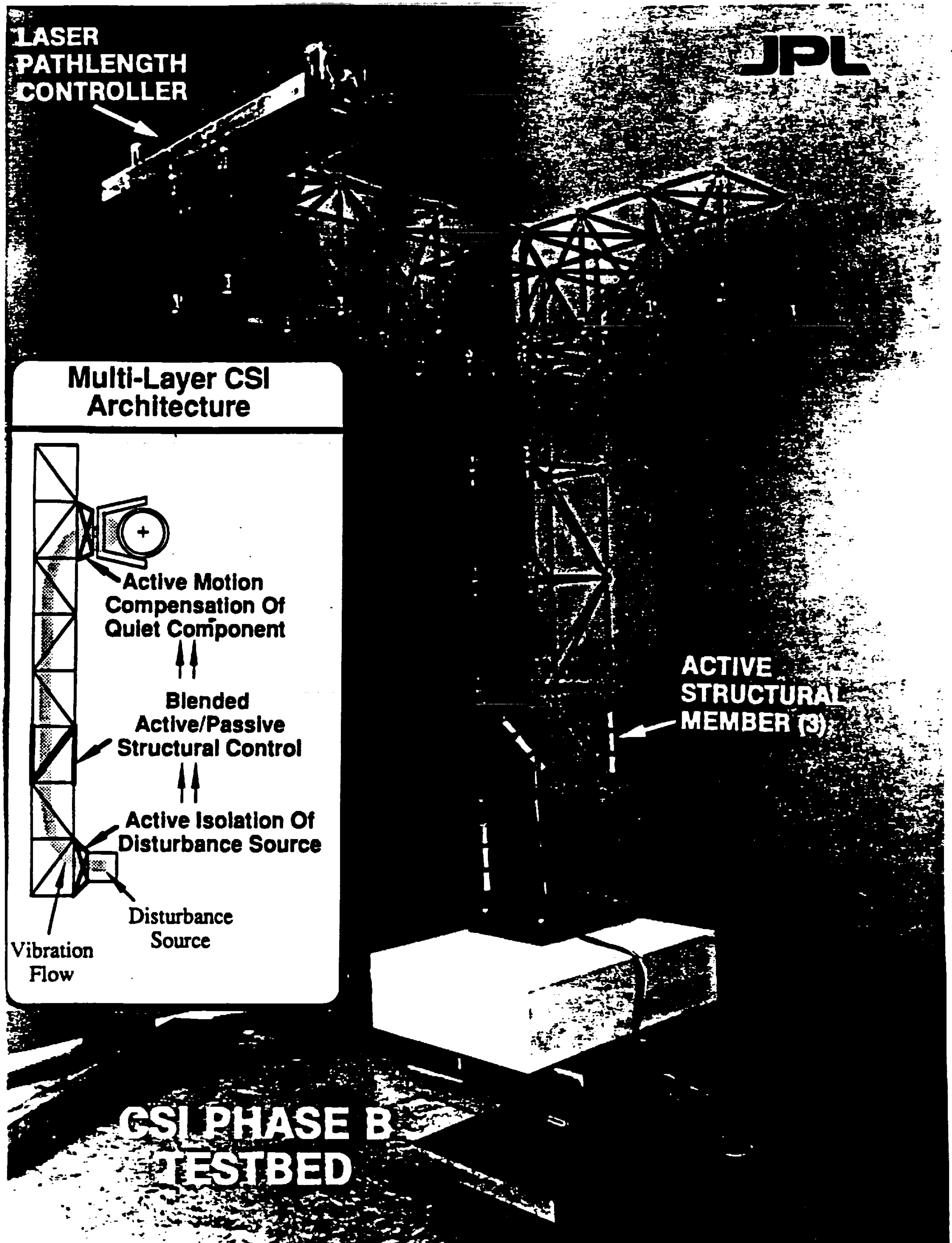


PATHLENGTH JITTER ENVELOPE DUE TO HST RW DISTURBANCE

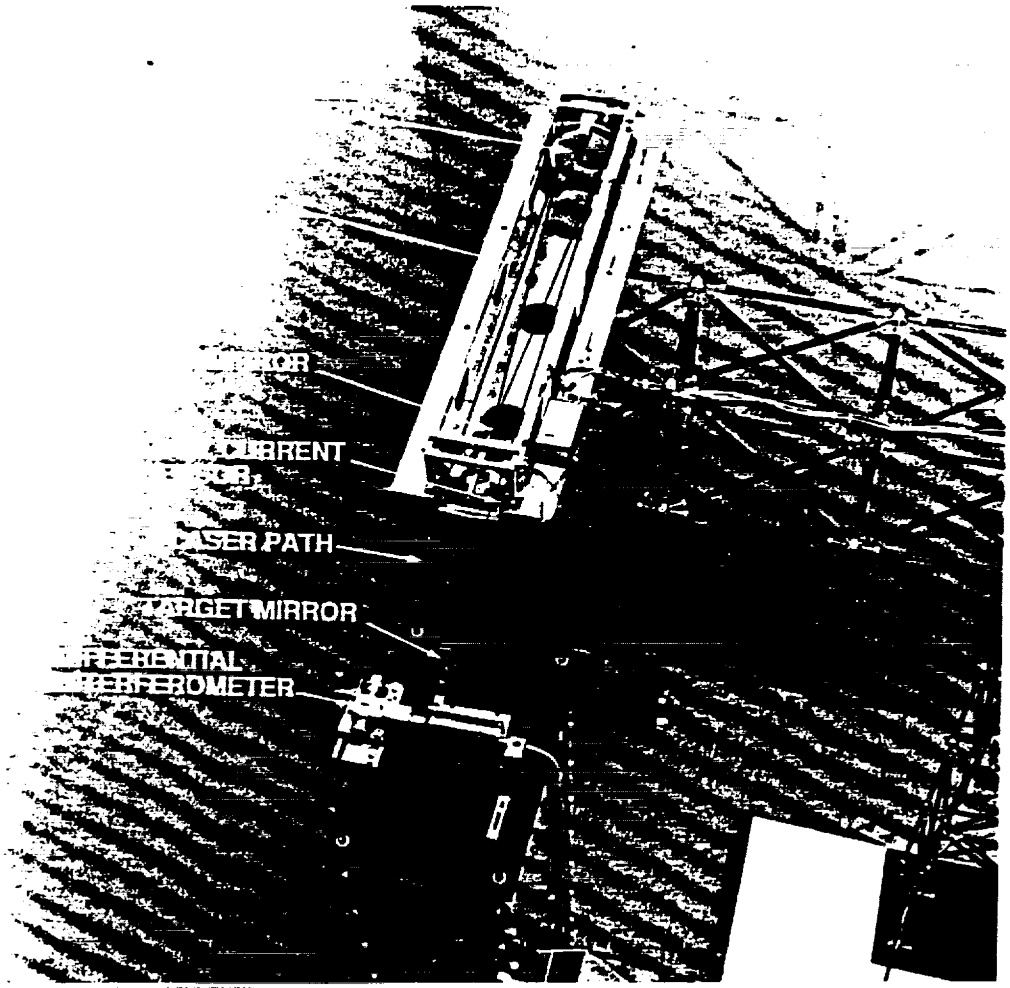


WHAT MUST CSI PROVIDE FOR THE COMING LARGE OPTICS MISSIONS

- VIBRATION REDUCTION FACTORS BETWEEN 10^3 AND 10^4
- OPERATION IN THE MICRODYNAMIC REGIME
- VALIDATED TECHNOLOGY, PROVEN READY TO FLIGHT MISSION PLANNERS

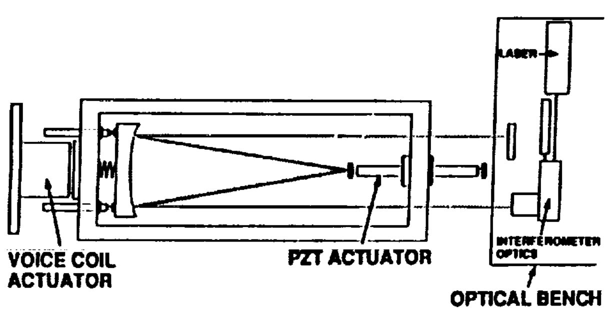

LASER
PATHLENGTH
CONTROLLER
JPL
Multi-Layer CSI
Architecture
Active Motion
Compensation Of
Quiet Component
Blended
Active/Passive
Structural Control
Active Isolation Of
Disturbance Source
Disturbance
Source
Vibration
Flow
ACTIVE
STRUCTURAL
MEMBER (3)
CSI PHASE B
TESTBED

CSI PHASE B TEST BED
OPTICAL MOTION COMPENSATION SYSTEM

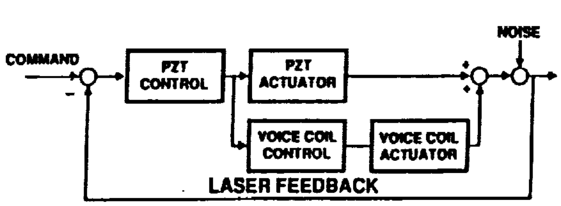


CSI OPTICAL COMPENSATION LAYER

DELAY LINE SCHEMATIC

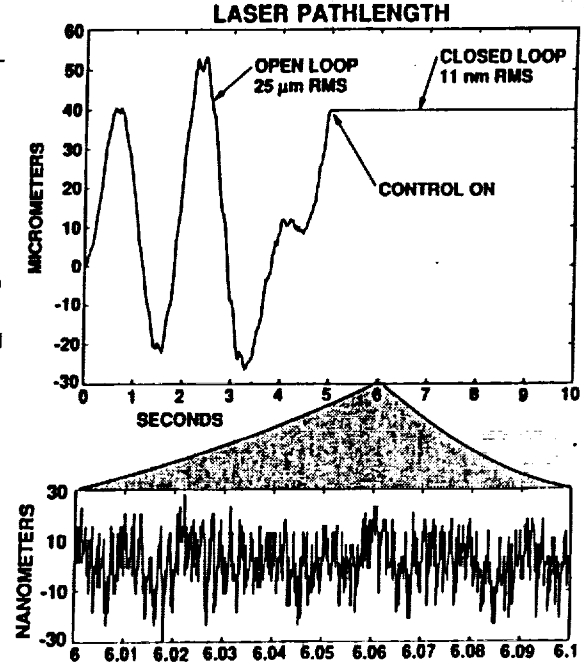


CONTROL SYSTEM BLOCK DIAGRAM

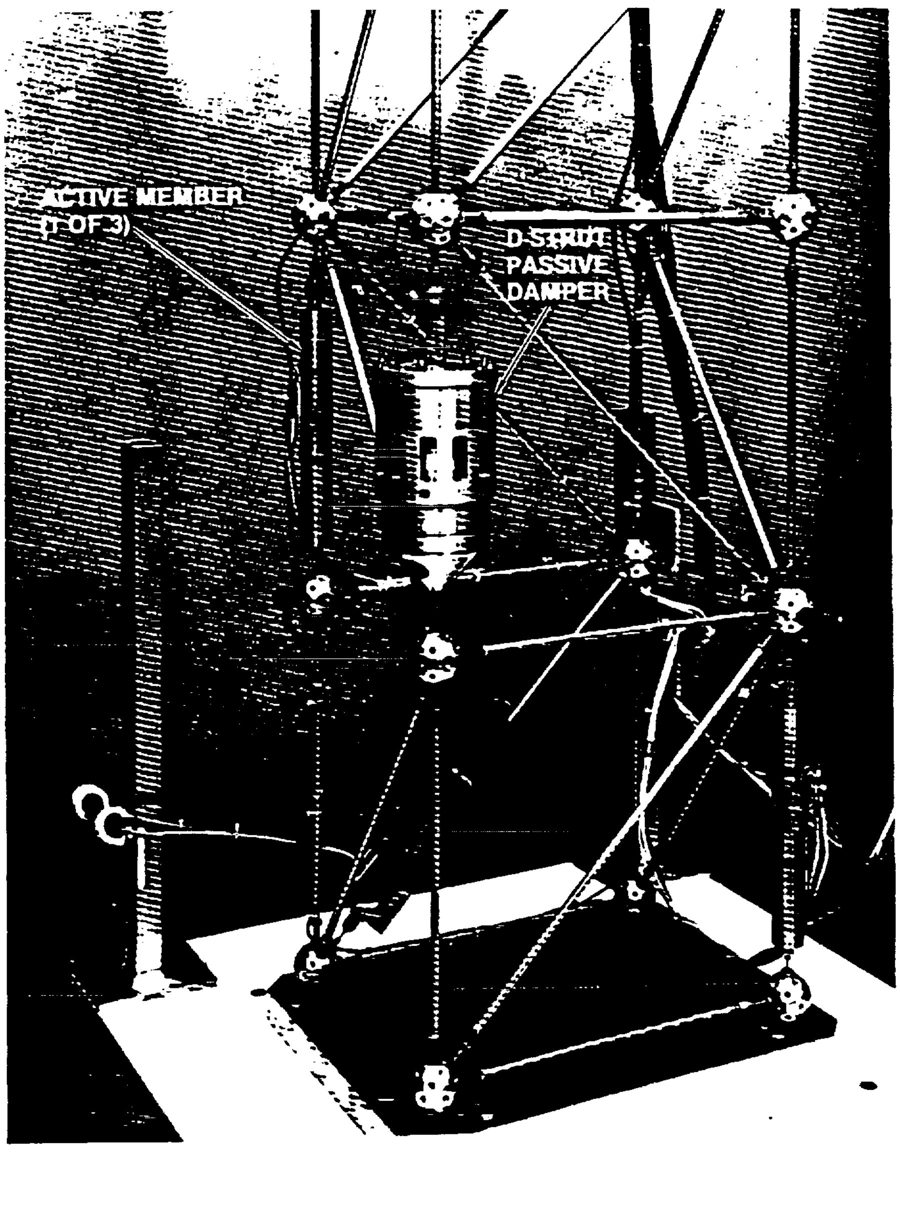


EXPERIMENTAL RESULTS

LASER PATHLENGTH

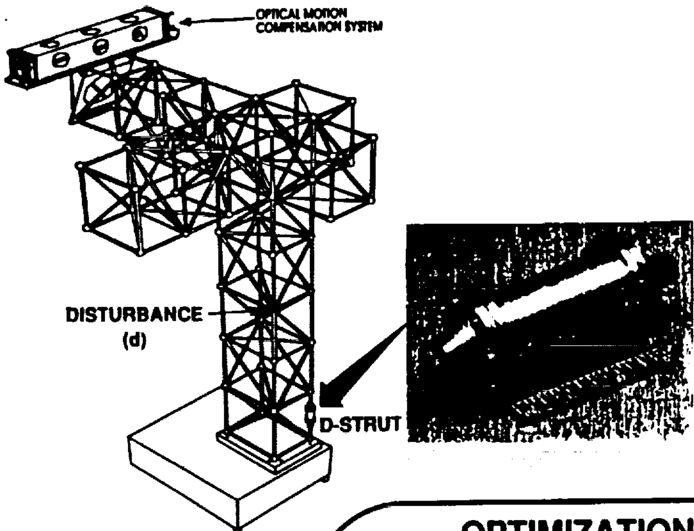


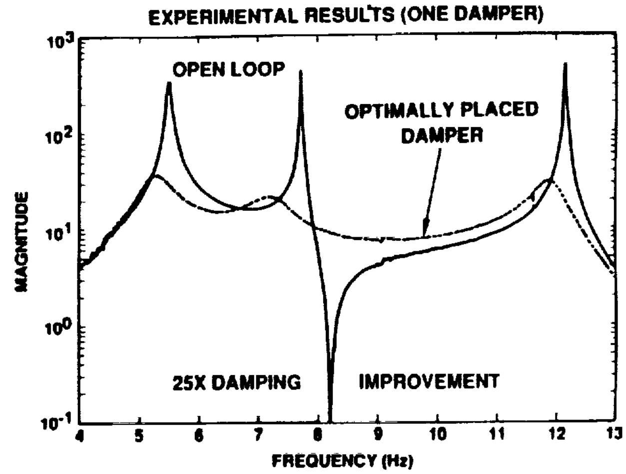
JPL CSI ACTIVE STRUCTURE CLOSEUP OF ACTIVE BAYS



OPTIMAL PLACEMENT AND TUNING OF PASSIVE ELEMENTS

JPL





OPTIMIZATION STRATEGY

$$\min_{b} \int_0^{\infty} E(x, \dot{x})\, dt$$

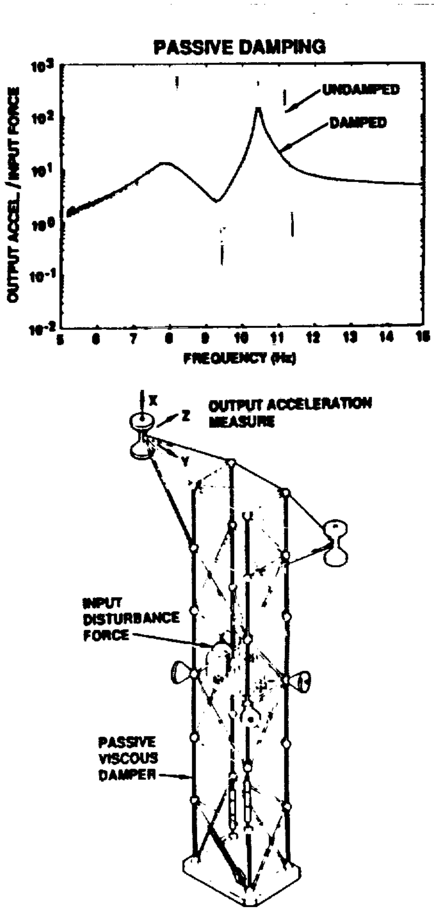
$$M\ddot{x} + (D + bb^T)\,\dot{x} + (K + bb^T)\,x = d$$

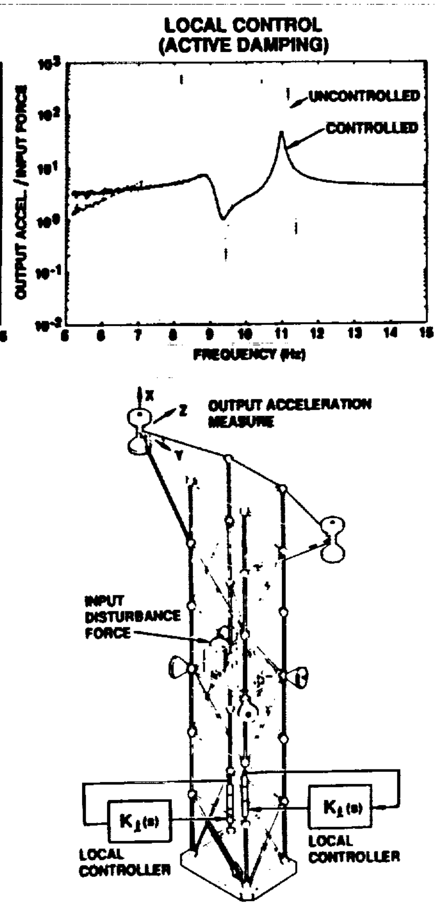
- FINITE ELEMENT MODEL CORRELATION
- MODEL REDUCTION
- SIMULATED ANNEALING

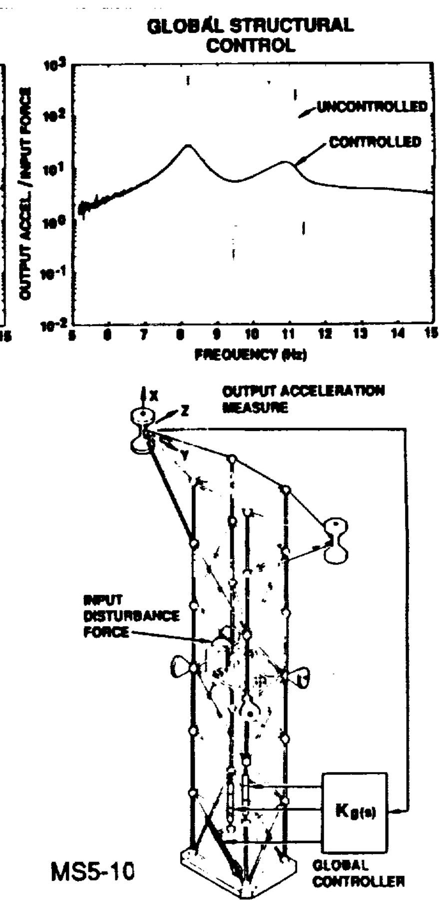
* METHOD APPLICABLE TO MULTIPLE PASSIVE AND ACTIVE ELEMENTS

CSI STRUCTURAL QUIETING TECHNOLOGY STUDIES

JPL

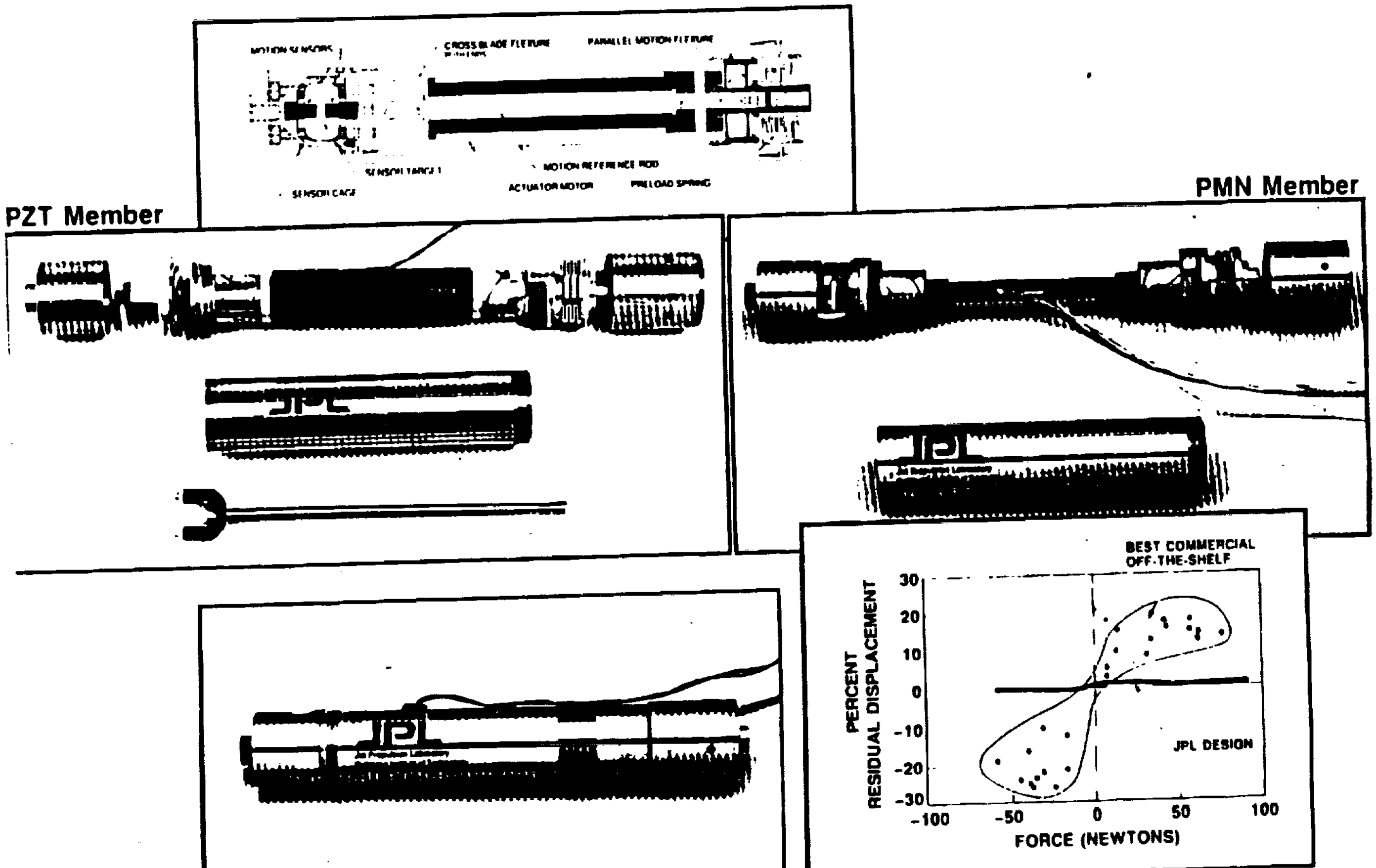






JPL

2ND GENERATION ACTIVE MEMBER



Inelastic Behavior

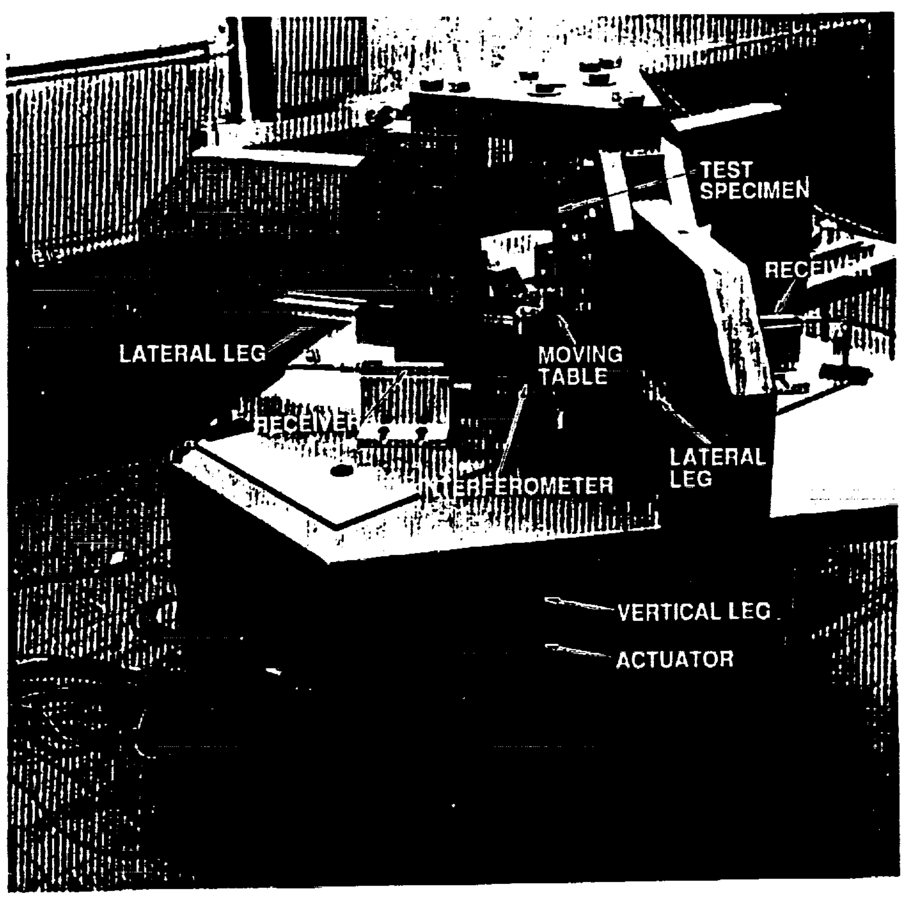
WHAT MUST CSI PROVIDE FOR THE COMING LARGE OPTICS MISSIONS

- VIBRATION REDUCTION FACTORS BETWEEN 10^3 AND 10^4
- OPERATION IN THE MICRODYNAMIC REGIME
- VALIDATED TECHNOLOGY, PROVEN READY TO FLIGHT MISSION PLANNERS

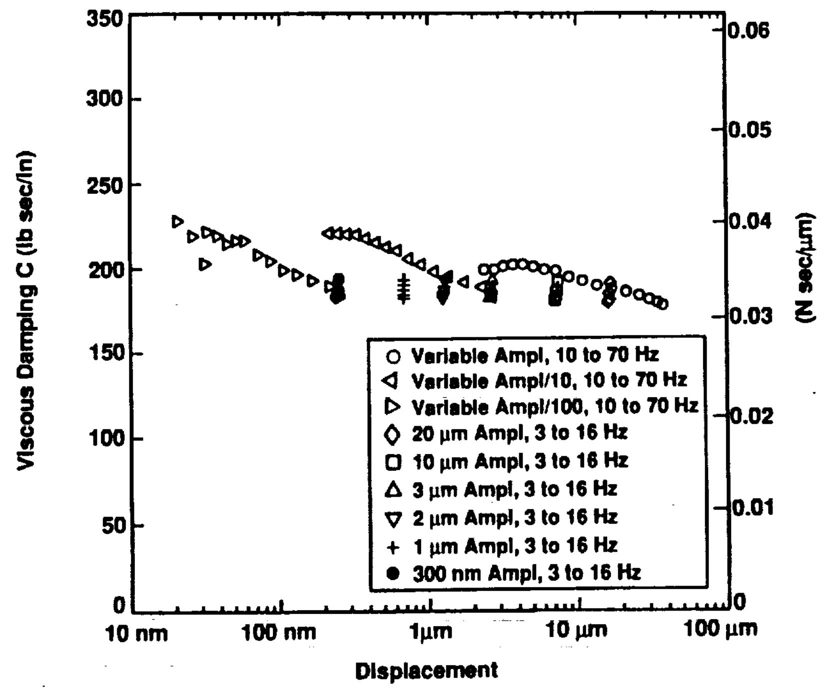
Microdynamic Test Machine

- **The Joint Test Experiment has Grown Into a Microdynamic Testing Capability**
  - -- Originally Intended to Find Linear Joining Techniques
  - -- Have Developed a General Purpose Microdynamic Test Capability
- **Current Capability**
  - -- Measure Axial Force and/or Two Bending Moments
  - -- DC Force Measurement to 0.01 N
  - -- AC Force Measure 40 N to ± 0.002 N or 0.75 N to ± 0.00002 N
  - -- Measure Axial Diaplacement and Two Angles
  - -- Displacement 200 μm to 1.25 nm, angle 300 to 0.001 arcsec
  - -- Frequency Response Flat to 70 Hz with 30 N/μm Specimen

MICRODYNAMIC TESTER CONFIGURATION



JPL D- STRUT TEST IN MICRODYNAMIC TESTER



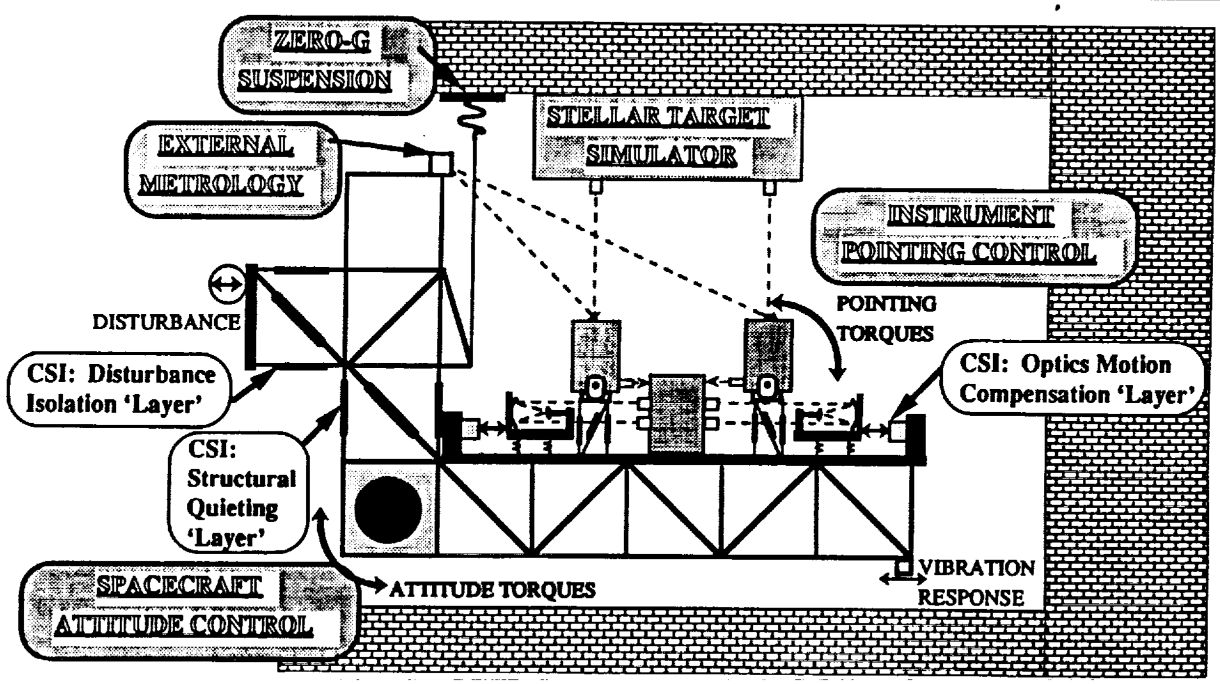
WHAT MUST CSI PROVIDE FOR THE COMING LARGE OPTICS MISSIONS

- VIBRATION REDUCTION FACTORS BETWEEN 10^3 AND 10^4

- OPERATION IN THE MICRODYNAMIC REGIME

- VALIDATED TECHNOLOGY, PROVEN READY TO FLIGHT MISSION PLANNERS

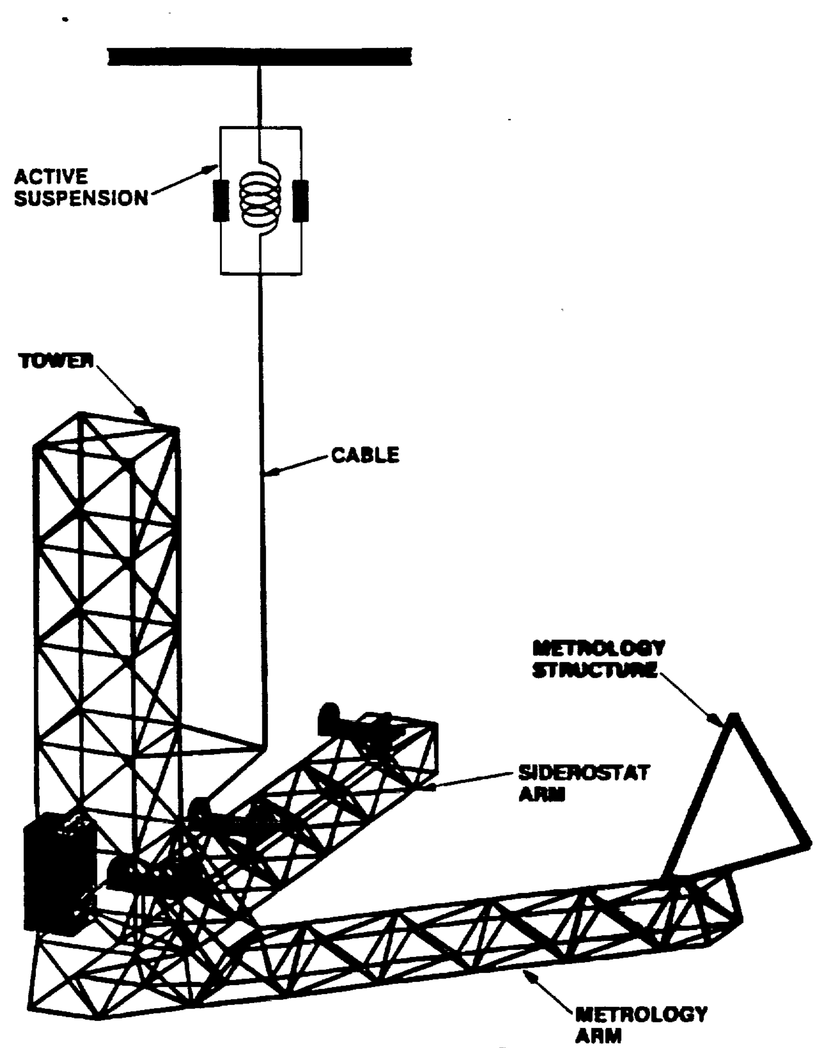
Micro-Precision CSI Technology...Verification Testing

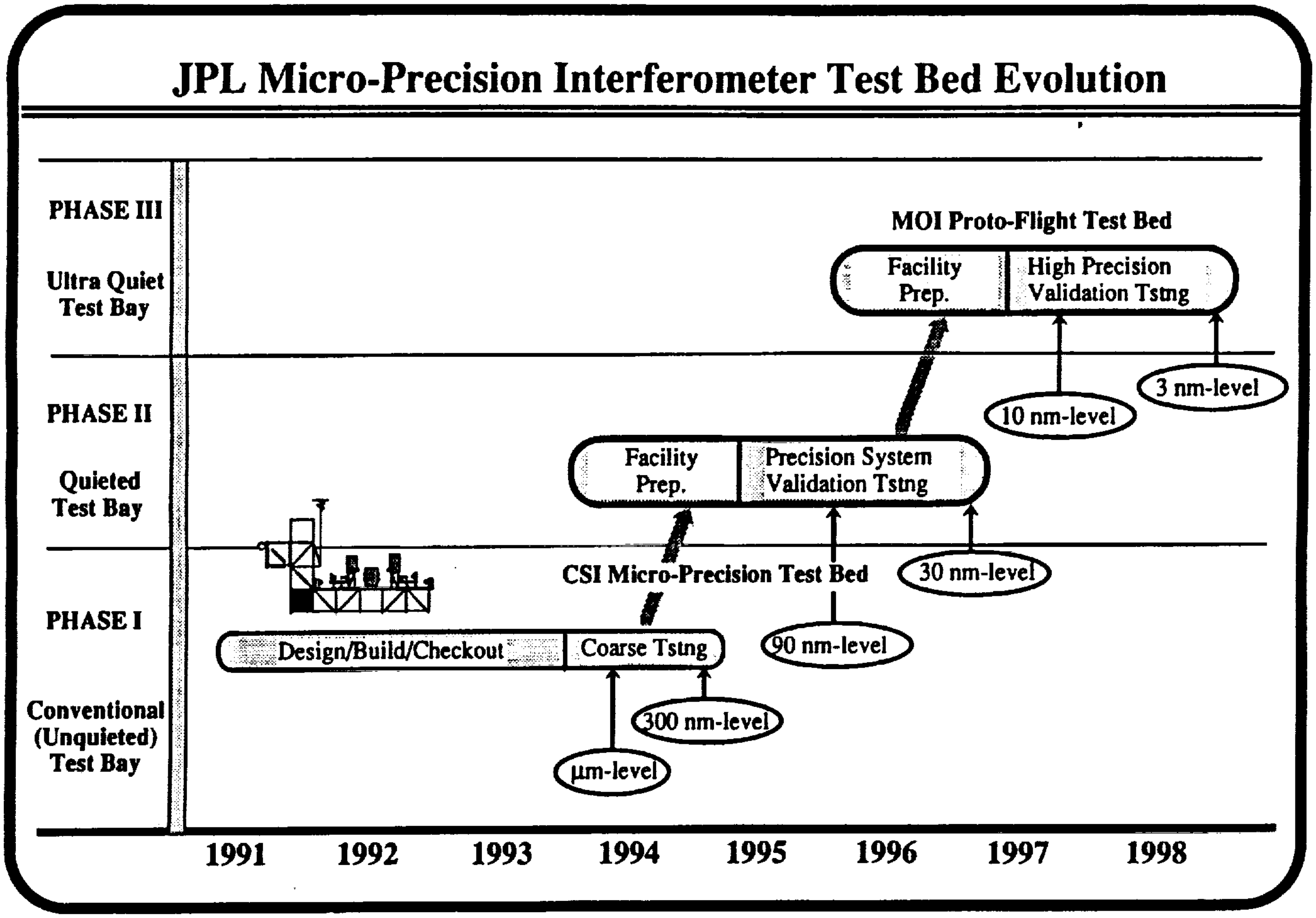


Micro-Precision Interferometer Testbed

End To End Space Interferometer Operation: System Level CSI Performance Proof

JPL TEST BED CONCEPT





3/91 RAL

Major On-Going Work

FY 91

- **Initial Validation Testing of Multi-Layer CSI Architecture on Phase B Testbed**
- **Initial Validation of Actuator Placement/Tuning on Phase B Testbed**
- **Microdynamic Component Tester Documented via Users Guide**
- **Initiate Micro-Precision Testbed Procurements**

FY 92

- **Update FMI CSI Benefits Study**
- **Advanced Validation Testing of Multi-Layer CSI Architecture and Actuator Placement/Tuning**
- **Review JPL Integrated Optimization Effort in NASA-Wide Context**
- **Micro-Precision Testbed Optics/Control Systems Critical Design Review**

FY 93

- **Initial Validation Testing of Integrated Optimization Tool on Phase B Testbed**
- **Micro-Precision Testbed Ready for Initial Coarse Testing**

Beyond

- **Micro-Precision Testbed Operational at Relevant Performance Levels**
  - End-to-End System Performance Demonstrated
  - FMI/MOI Specific Design Trades Explored
- **Integrated Optimization Tool Validated on Micro-Precision Testbed**

Micro-Precision CSI Augmentations

- INTEGRATED CONTROL/STRUCTURE/OPTICS/THERMAL MODELING AND DESIGN ENVIRONMENT
- NANO-METROLOGY DEVELOPMENT FOR INTERFEROMETRY SCIENCE AND STRUCTURAL CONTROL
- NATIONAL LEVEL MICRODYNAMIC COMPONENT TEST PROGRAM
- HIGH PRECISION MULTI-INPUT MULTI-OUTPUT (MIMO) SYSTEM IDENTIFICATION AND MODEL CORRELATION METHODS
- PROTOFLIGHT ACTIVE MEMBER DEVELOPMENT

AUGMENTED MICRO-PRECISION CSI NEW PROGRAM TARGET MILESTONES.

FY93
- Prototype Integrated Control/Structure/Optics/Thermal Design Tool
- 10 Nanometer Metrology Demonstrated in 5 Meter Optical Truss

FY94
- MIMO Model Correlation Demonstrated on Phase B Testbed
- 1 Nanometer Metrology Demonstrated in 5 Meter Optical Truss

FY95
- Interim Report - National Microdynamic Component Test Program
- Active Member Flight Qualified Design Complete

FY96
- JPL Guest Investigator(s) Final Reports
- Integrated Design Tool Beta Software Release
- 0.1 Nanometer Metrology Demonstrated in 5 Meter Optical Truss

FY97
- MIMO Model Correlation Demonstrated on Micro-Precision Testbed
- Active Member Flight Qualified
- Integrated Design Tool Version 1.0 Software Release
- Final Report - National Microdynamic Test Program

Strategic	FY 92	FY 93	FY 94	FY 95	FY 96	FY 97
($K)	4000	6600	7700	9200	10200	10700

SUMMARY

- NASA CSI TECHNOLOGY IS THE LEADING EDGE IN MICRO-PRECISION CONTROLLED STRUCTURES

- MICRO-PRECISION CSI IS WELL TIED IN TO THE CODE S USER COMMUNITY

THE CSI PROGRAM AT JPL IS...

- AN INTEGRATED PROGRAM WITH A COMMON FOCUS

- A COLOCATED COLLECTION OF JPL's "BEST AND BRIGHTEST"

- INVOLVED IN NUMEROUS COLLABORATIVE EFFORTS WITH NASA, INDUSTRY, AND ACADEMIA

- READY TO IMPLEMENT THE MICRO-PRECISION INTERFEROMETER TESTBED

56-81

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p. 17

INTEGRATED TECHNOLOGY PLAN FOR THE CIVIL SPACE PROGRAM

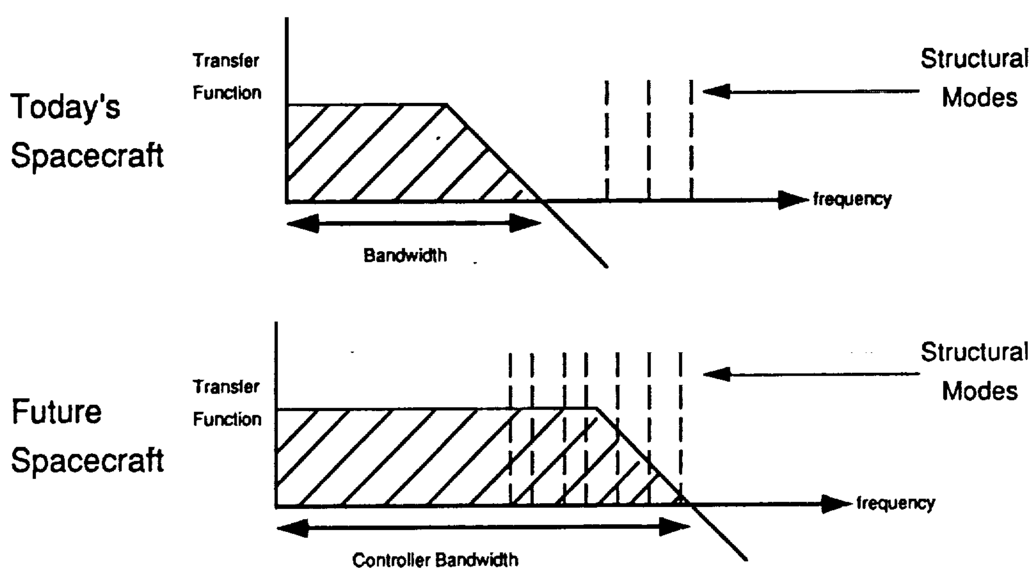
CONTROLS-STRUCTURES INTERACTION (CSI) TECHNOLOGY PROGRAM SUMMARY

EARTH ORBITING PLATFORMS PROGRAM AREA OF THE SPACE PLATFORMS TECHNOLOGY PROGRAM

Jerry R. Newsom
NASA LaRC
June 26, 1991

CONTROLS- STRUCTURES INTERACTION

- CSI technology embraces the understanding of the interaction between the spacecraft structure and the control system, and the creation and validation of concepts, techniques and tools for enabling the interdisciplinary design of an integrated structure and control system, rather than the integration of a structural design and a control system design. (SSTAC 1987)



CONTROLS-STRUCTURES INTERACTION (CSI) TECHNOLOGY

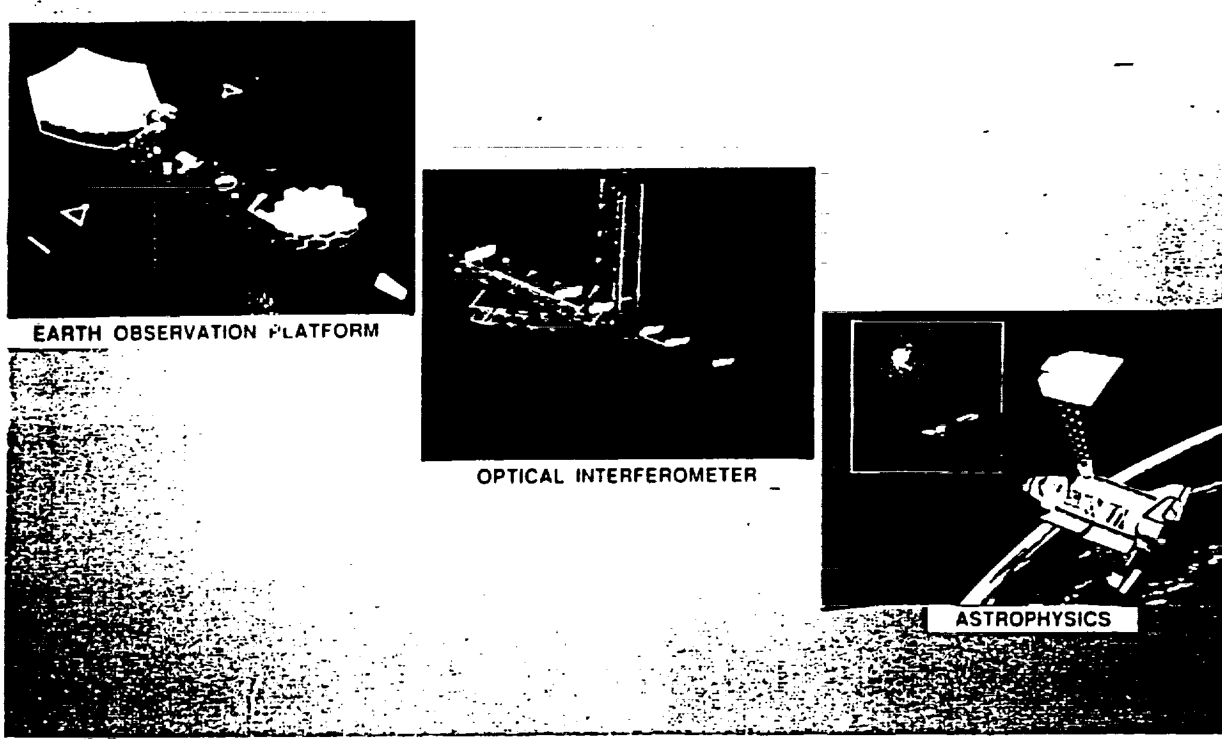
GOAL:

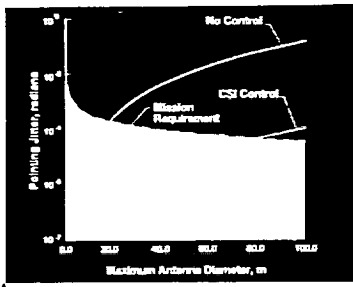
DEVELOP VALIDATED CSI TECHNOLOGY FOR INTEGRATED DESIGN/ANALYSIS AND QUALIFICATION OF LARGE FLEXIBLE SPACE SYSTEMS AND PRECISION SPACE STRUCTURES

OBJECTIVES:

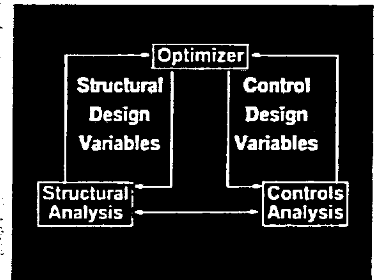
- To provide spacecraft dynamic response amplitude reductions of 50 percent, for any input or maneuver, with minimum increase in system mass.
- To enable the use of wide-bandwidth CSI control systems to achieve several orders of magnitude improvement in control and pointing capabilities.
- To predict the on-orbit performance of CSI systems within 10 percent of all amplitude, frequency, time and stability requirements based on the results of integrated analyses tuned/corrected by closed-loop ground and/or flight test data.
- To develop unified controls-structures modeling, analysis and design methods which allow a complete iteration on all critical design variables in a single integrated computational framework.
- To develop the capability to validate the performance of flight systems by analysis/ground tests.

CSI PROGRAM FOCUS MISSIONS





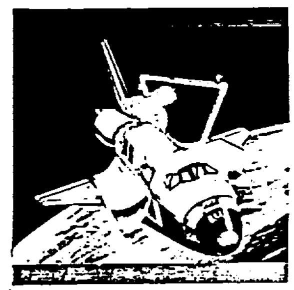
System Studies



Integrated Design Methods

Ground Test Methods

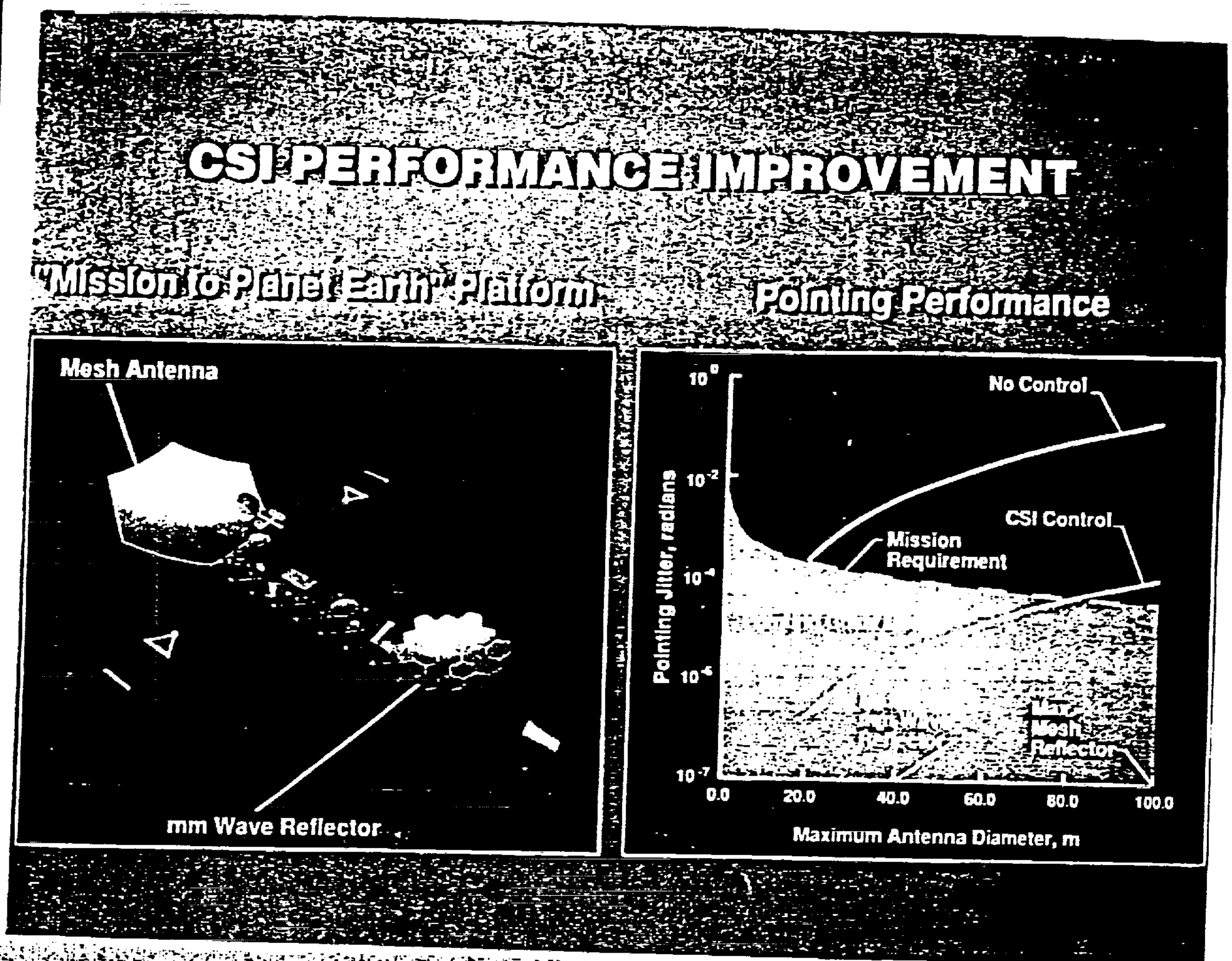
Guest Investigators

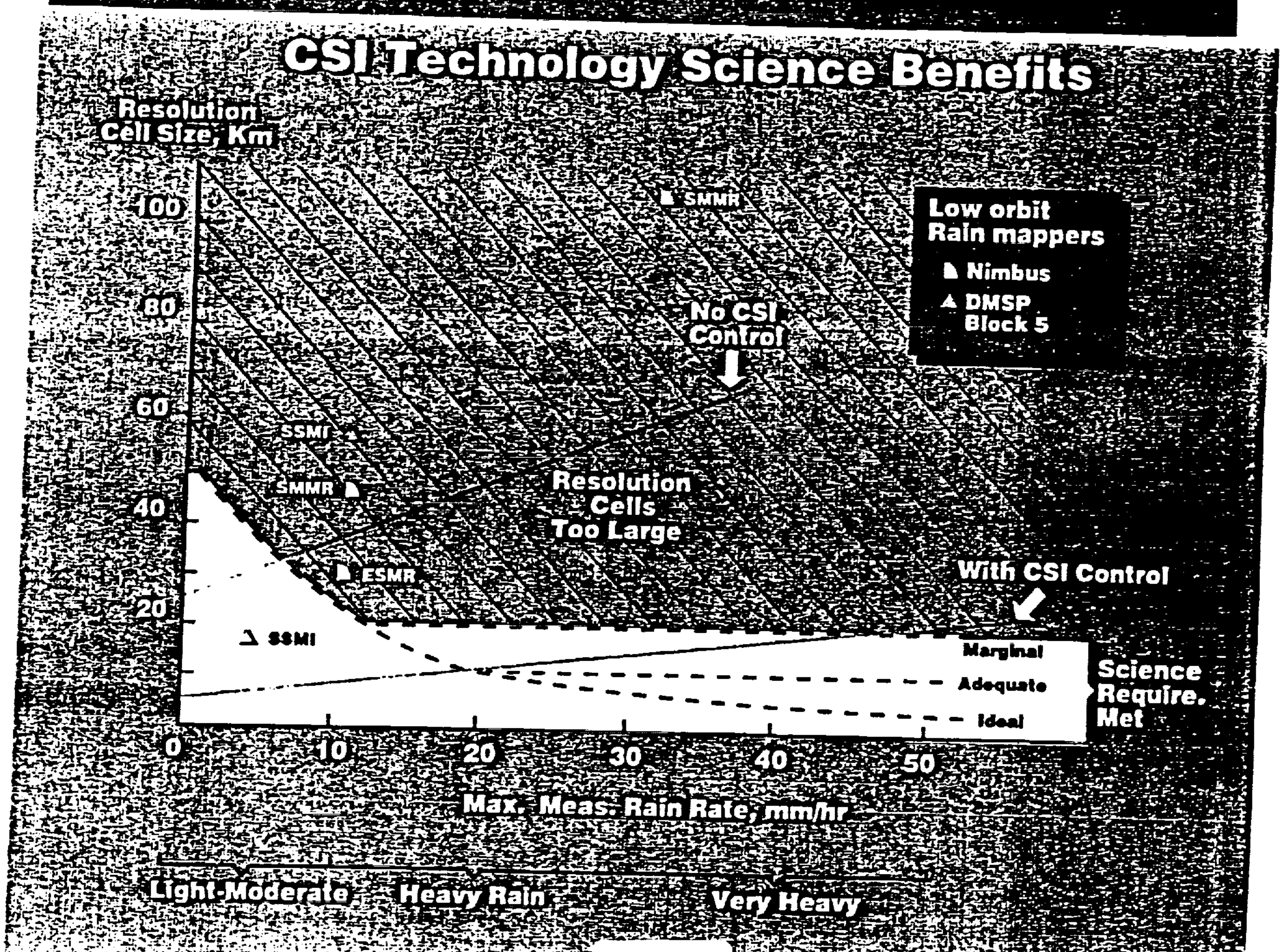


Flight Experiments

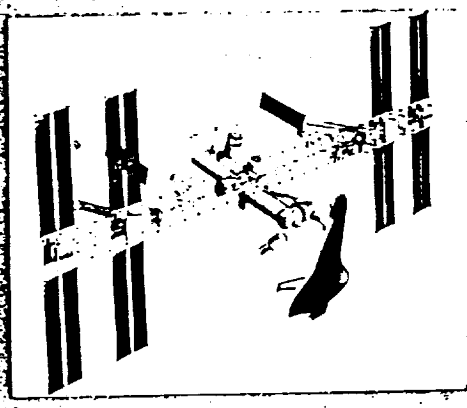
BENEFITS STUDY

- PURPOSE: To Quantify the Specific Advantages of CSI Technology for Future Missions Requiring Large Space Structures.
- APPROACH: Select a Future NASA Mission and Define Differences in the Spacecraft Design and Performance Capability Using Both the Conventional and CSI Approach.
- EXAMPLES: (1) Geostationary Platform
  (2) Shuttle RMS
  (3) Multipayload Platform

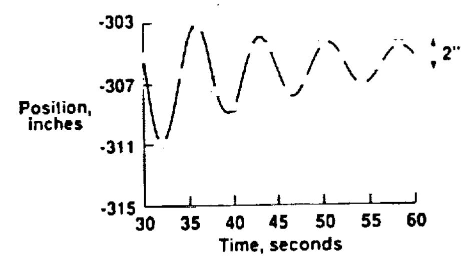

CSI PERFORMANCE IMPROVEMENT
"Mission to Planet Earth" Platform
Pointing Performance
Mesh Antenna
mm Wave Reflector
No Control
CSI Control
Mission Requirement
Max. Mesh Reflector
Pointing Jitter, radians
Maximum Antenna Diameter, m
0.0
20.0
40.0
60.0
80.0
100.0


CSI Technology Science Benefits
Resolution Cell Size, Km
Low orbit Rain mappers
Nimbus
DMSP Block 5
SMMR
No CSI Control
SSMI
SMMR
Resolution Cells Too Large
ESMR
SSMI
With CSI Control
Marginal
Adequate
Ideal
Science Require. Met
100
80
60
40
20
0
10
20
30
40
50
Max. Meas. Rain Rate, mm/hr
Light-Moderate
Heavy Rain
Very Heavy

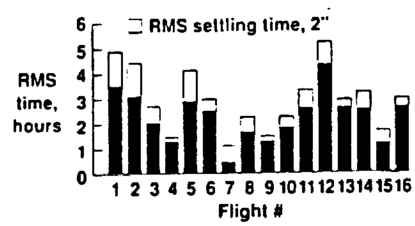
POTENTIAL SPACE STATION ASSEMBLY BENEFITS DUE TO CSI (Timeline)



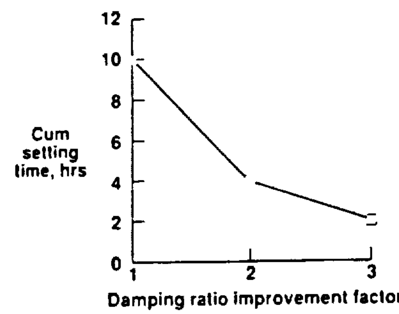
Draper RMS Simulator response
Payload 3500 lbs



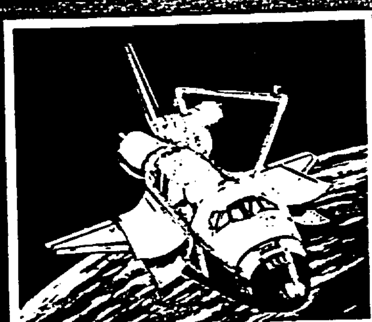
RMS settling time



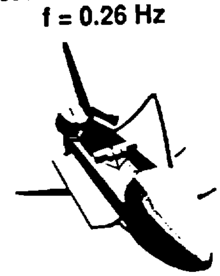
Potential CSI benefits



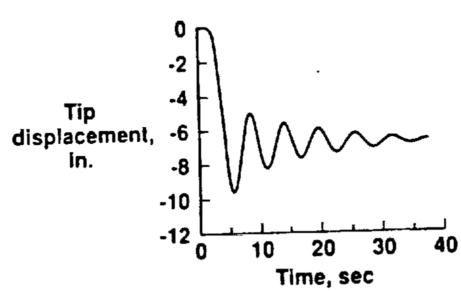
ACTIVE VIBRATION CONTROL OF THE SHUTTLE RMS



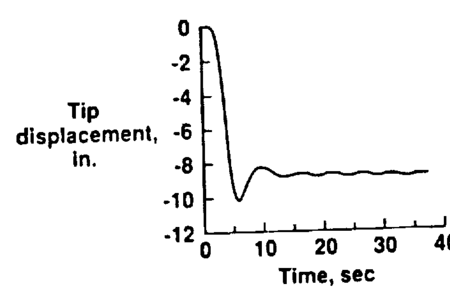
Typical RMS flexible mode
f = 0.26 Hz



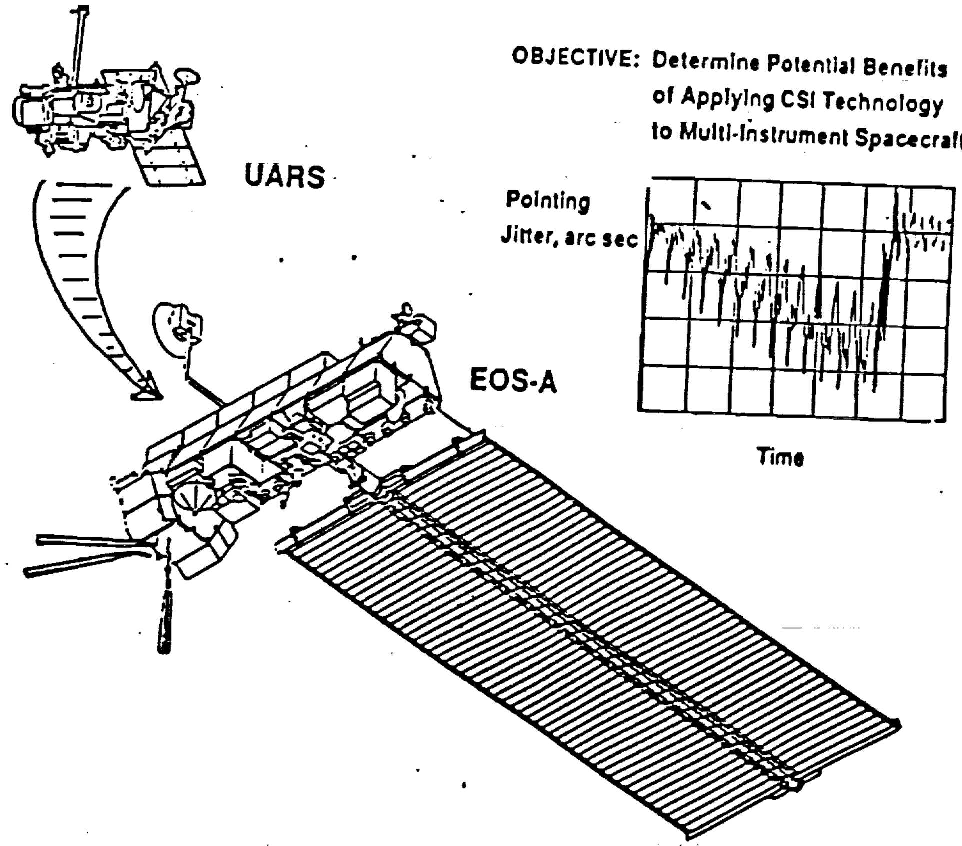
TIP response
without active vibration control



TIP response
with active vibration control



MULTI-PAYLOAD PLATFORM CSI STUDY



GROUND TESTS AND TEST METHODS

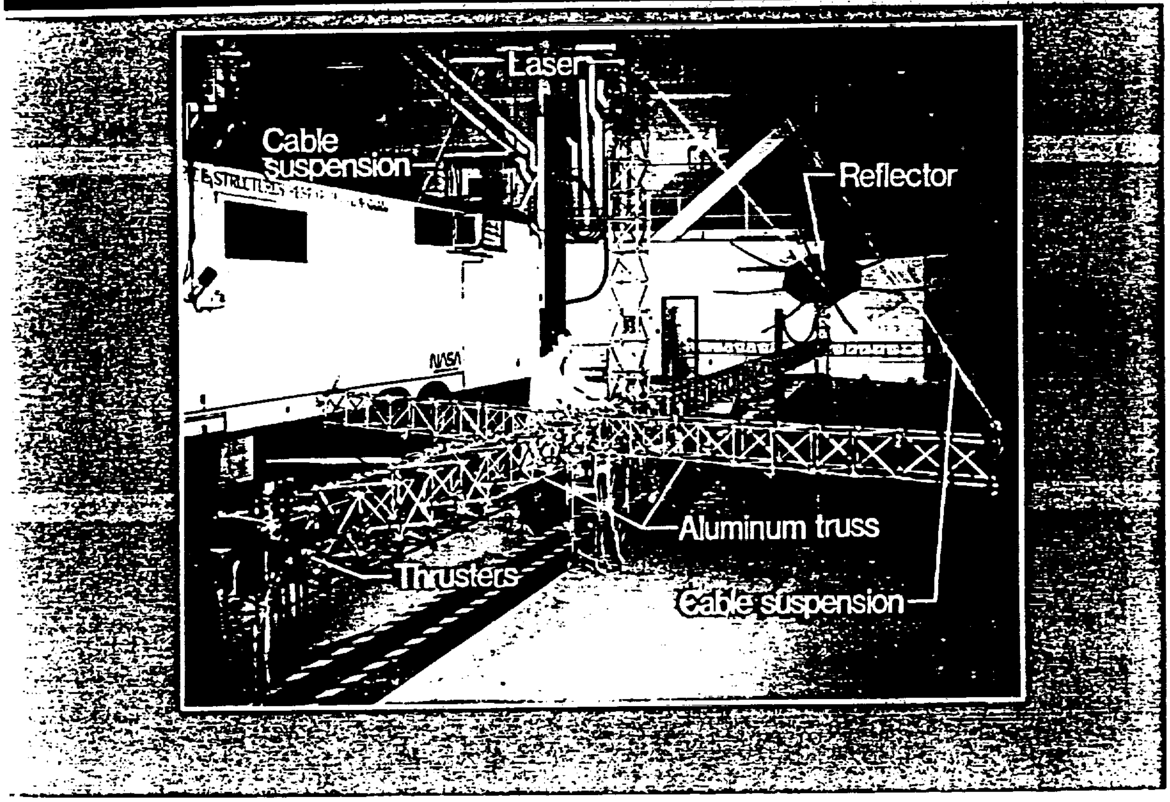
Objectives

- To ascertain the applicability of theoretical CSI developments to complex hardware systems
- To develop ground test methods suitable for verifying that CSI spacecraft systems are adequate for flight

Approach

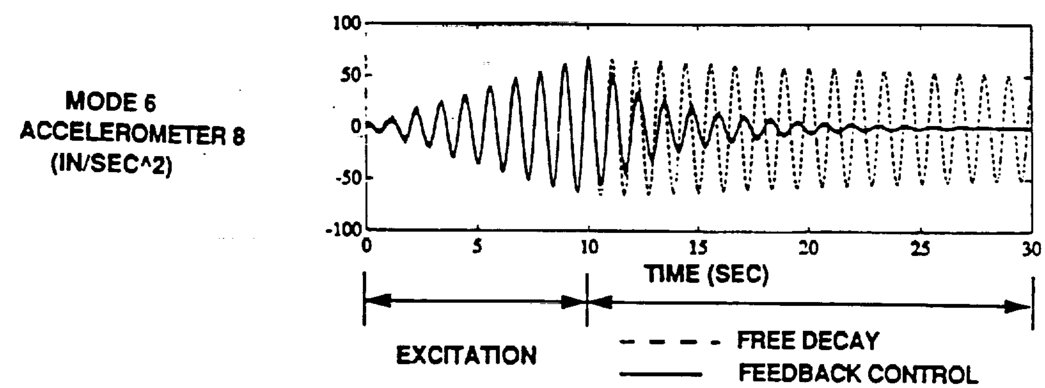
- Develop hardware testbeds
- Perform in-house analysis and tests
- Conduct guest-investigator studies

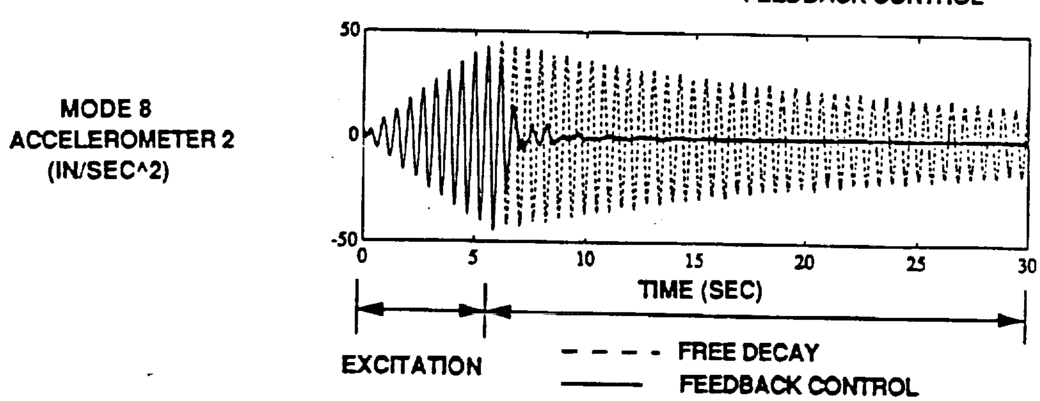
THE PHASE-ZERO EVOLUTIONARY MODEL: A CONTROLS-STRUCTURES INTERACTION TESTBED



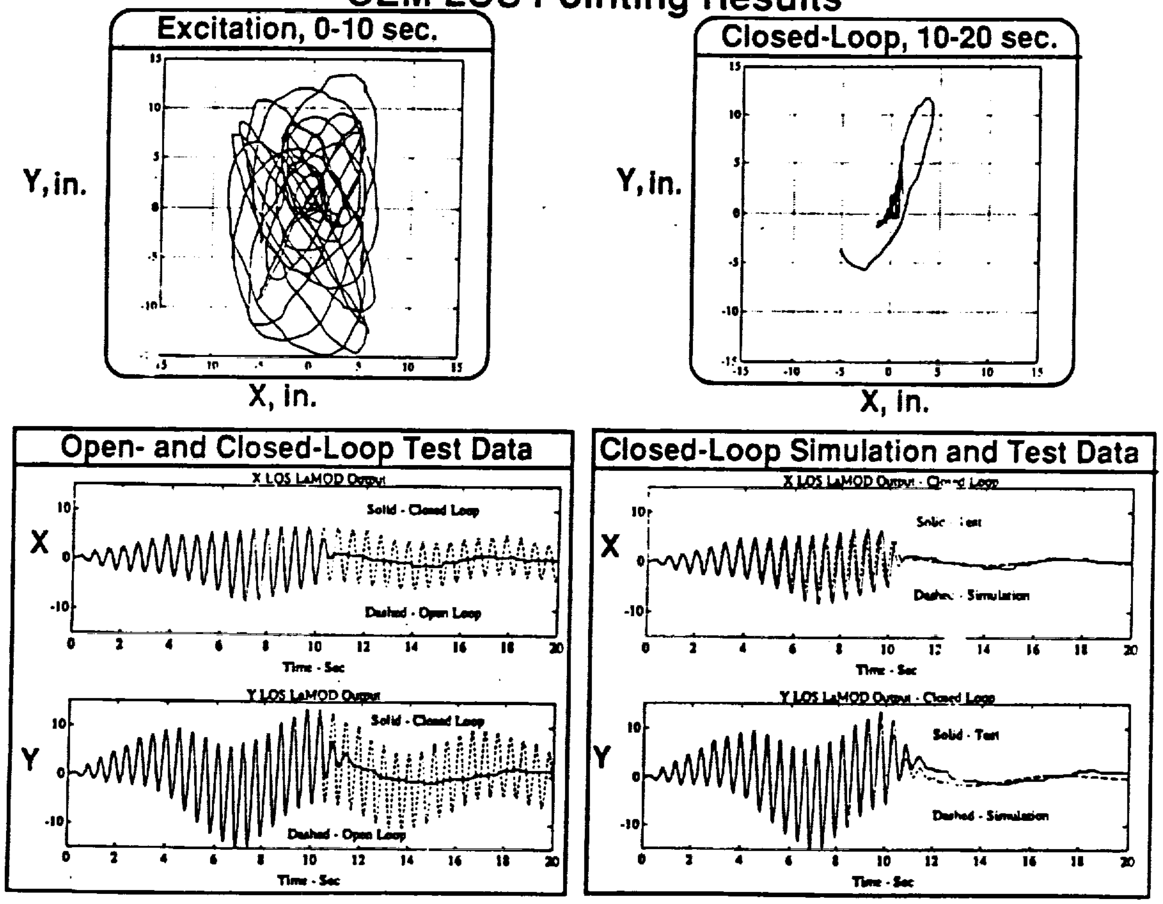
EXPERIMENTAL RESULTS

OPEN AND CLOSED-LOOP RESPONSES

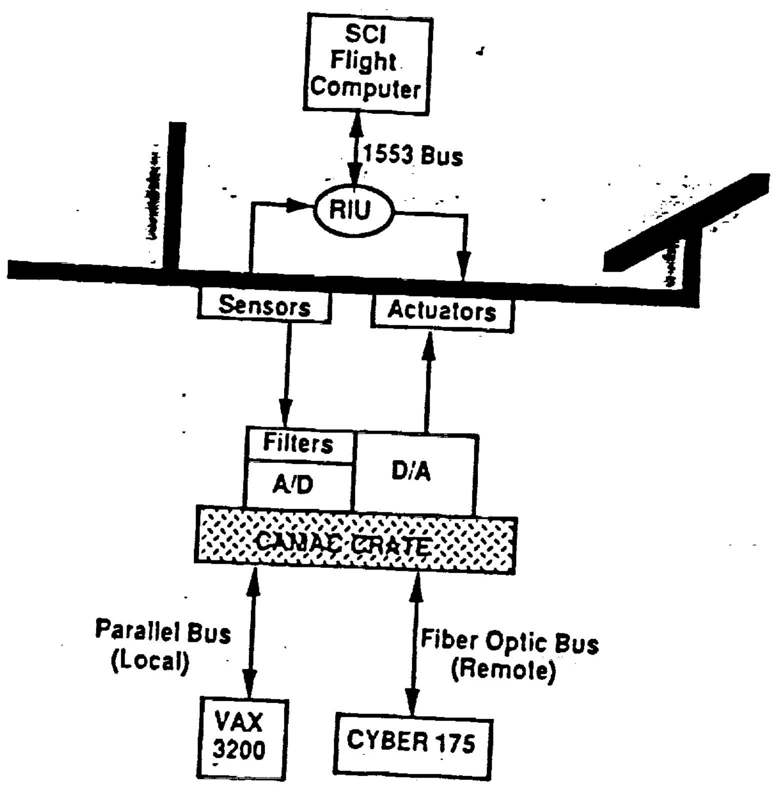




CEM LOS Pointing Results



Real-Time Computer Hardware



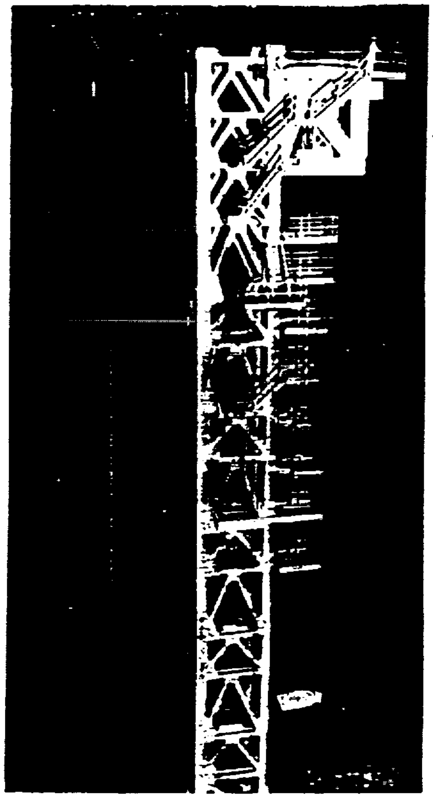
SOFTWARE DEVELOPMENT OVERVIEW

- Entire software system developed at Langley (ACD/FSGB)
  - Real-Time Executive, Interfaces, Applications
  - RIU and 1553B interface software developed jointly with SED
- Software for all 1750A's and PC/AT will be written in Ada
- This is Langley's first production Ada project
- Similar Ada based 1750A systems are proposed for EOS missions
- Software system designed using object-orientated design methods
  - Allows software to evolve in step with hardware system
  - Testbed modules can be reused on future missions (CSI, EOS)
- Believed to be one of the first real-time distributed Ada based 1750A production systems anywhere.

GTM Testbed Description/Goals

Phase 0 **Global LOS Pointing objective.** **Uniform structure.** **500 micro radians accuracy.** **Active only, 8 accels, 8 thrusters.**	***Implement LAC/HAC controller on structure with realistic dynamics of space platforms.***
Phase 1 **Global LOS Pointing objective.** **Integrated controller & structure.** **500 micro radians accuracy.** **Active only, 8 accels, 8 thrusters.**	***Quantify benefits of integrated controller & structure design and assess predictive accuracy.***
Phase 2 **Multi-Payload Pointing objective.** **Phase 1 structure.** **5 micro radians accuracy.** **24 piezo struts, 3 gimbals.**	***Implement distributed/centralized controllers for multi-payload platforms.***
Phase 3 **Multi-Payload Pointing objective.** **Redesigned structure.** **5 micro radians accuracy.** **24 piezo struts, 3 gimbals.** **100 passive struts,optimal sensor actuator placement.**	***Verify integration of passive, active smart systems with multi-objective controller.***
Phase 4 **Integrated controller & structure multi-payload free-flyer design.** **5 micro radians accuracy. Integrated passive and active sensors/actuators and on-board power and computers.**	***Ground test experiment for CSI Class 1 & 2 flight demonstration.***

CASES GTF (Ground Test Facility)



- **Status: Partially Operational**

  Test Articles: Boom, MPESS, Tip Plate completed
  Boom/MPESS suspended

  Disturbance System: Integration nearing completion

  Computer System: Delivered, Tested
  CASES Software being developed

  Sensors & Actuators:
  AMED system: Final testing prior to integration
  BLTs tested
  BMT/TDS design in progress
  Auxilliary sensors obtained (Accels, Force, etc...)

  Electronics: Several subsystems complete
  (Mux/Demux, Reaction Wheel, Gyro, etc....)

- **Baseline Operational: Aug/Sept 1991**

AMEDs	Angular Momentum Exchange Devices
BLTs	Bidirectional Linear Thrusters
BMT/TDS	Boom Motion Tracker/Tip Displacement Sensor
CASES	Controls, Astrophysics, and Structures Experiment in Space
MPESS	Mission Peculiar Experiment Support Structure

GUEST INVESTIGATOR PROGRAM

- **GOAL: OBTAIN BEST AVAILABLE CSI TECHNOLOGY EFFORT FROM RESEARCHERS IN ACADEMIA & INDUSTRY.**

- **APPROACH: GENERAL SOLICITATION OF PROPOSALS THROUGH NRA WITH INTERCENTER SELECTION TEAM.**

- **STATUS:**

  <u>Phase I</u> - Completed
  Eight Investigators
  Two Test Beds
  LaRC - Mini-MAST
  MSFC - Advanced Control Evaluation for Structures (ACES)

  <u>Phase II</u> - Joint Program with the Air Force, Edwards AFB
  101 Proposals Received
  Five Winners Announced December 1990
  Three Test Beds
  LaRC - CSI Evolutionary Model (CEM)
  MSFC - Control, Astrophysics, and Structures Experiment in Space (CASES)
  AF - Advanced Space Structure Technology Research Experiments (ASTREX)

PHASE 1 GUEST INVESTIGATOR PROGRAM

UNIVERSITY INDUSTRY	PRINCIPAL INVESTIGATOR	PRIMARY THRUST
CAL TECH	Dr. John Doyle	Noncollocated Controller Design
MIT	Dr. W. Vander Velde	Off-Line and On-Line Sys. ID Algorithms
PURDUE	Dr. Robert Skelton	Noncollocated Controller Design
U. CINCINNATI	Dr. Randall Allemang/ Dr. Slater	Off-Line System ID Algorithms
U. TEXAS	Dr. Bong Wie	Collocated/Noncollocated Controller Design
HARRIS	Dr. David Hyland	Noncollocated Controller Design
BOEING	Dr. Michael Chapman	Nonlinear Math Modeling
Dynamic Engin. /VPI	Wilmer Reed	Design of Passive and Active Suspension Systems

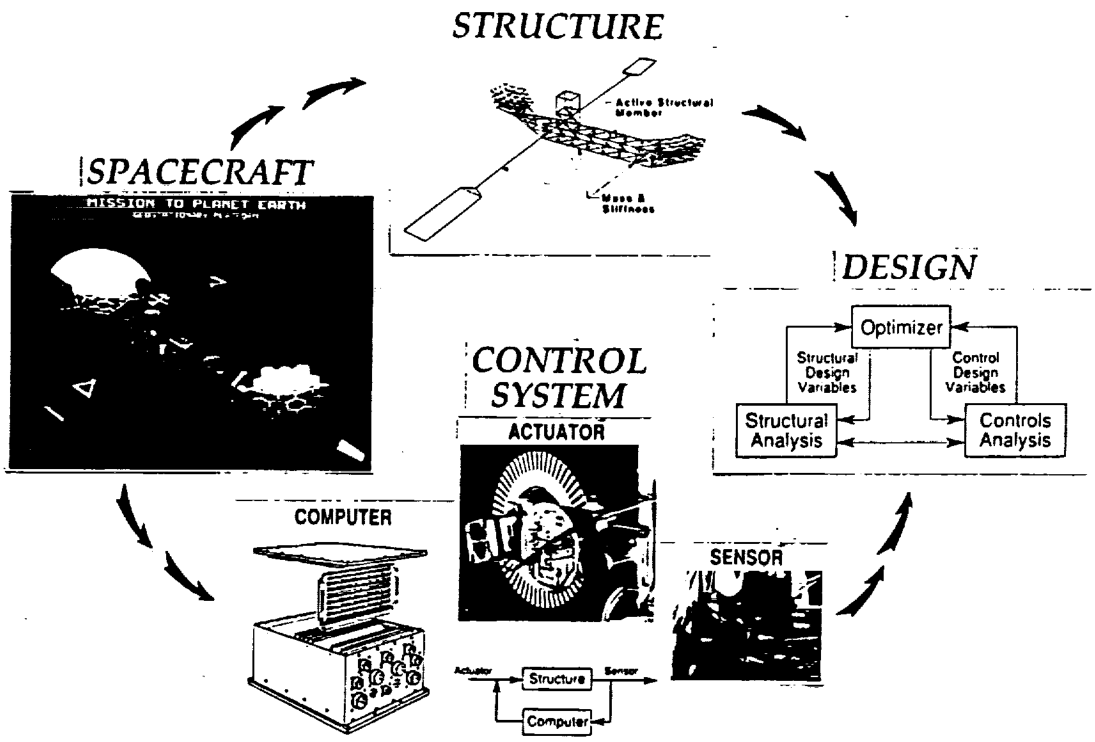
MAJOR LESSONS LEARNED

- Modeling sensors, actuators, and electronics as important as modeling structure
- Single-input single-output control design approach for flexible structure control can be effective
- System identification is an essential element for successful flexible structure control

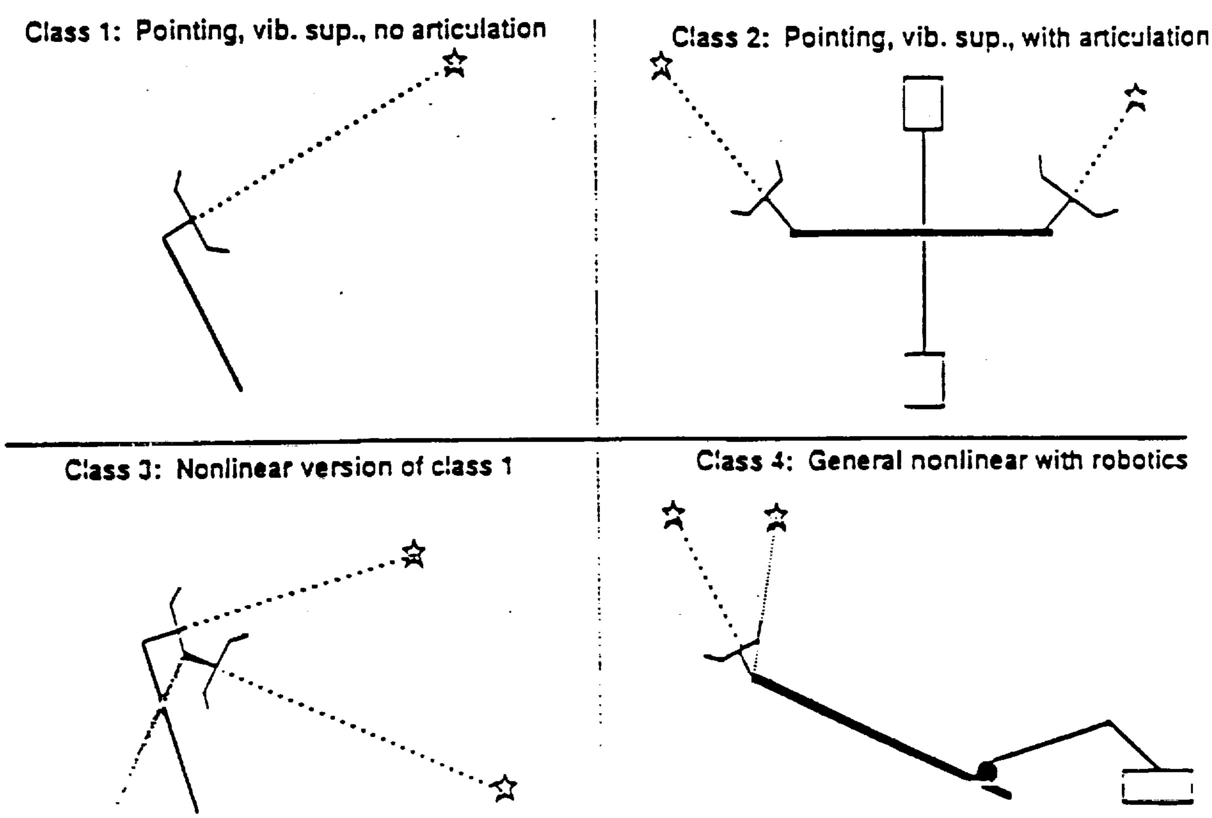
PHASE II GUEST INVESTIGATORS

UNIVERSITY/ INDUSTRY	PRINCIPAL INVESTIGATOR	PRIMARY THRUST (Facility)
Martin Marietta	Eric Schmitz	Smart Struts & Controller Design LaRC CSI Evolutionary Model
Harris Corporation	David Hyland	Noncollocated Controller Design MSFC Ground CASES
Boeing Aerospace	David Warren	CMG/RCS Pointing & Slewing Air Force ASTREX
MIT	Andy von Flotow	Passive Damping/Controller Design Air Force ASTREX
Texas A&M	Srinivas Vadali	Controller Design Air Force ASTREX

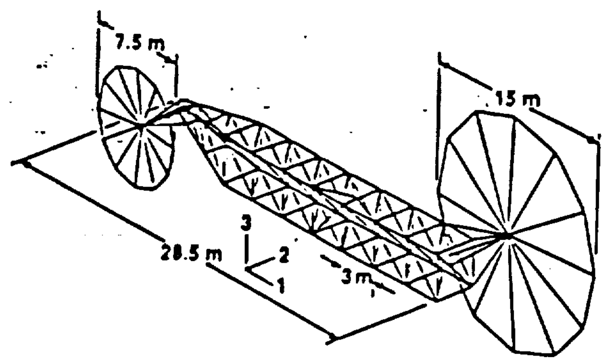
INTEGRATED STRUCTURE/CONTROL DESIGN



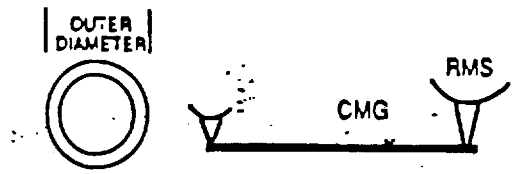
PROBLEM CLASSIFICATION



DESIGN PROBLEM I



- Design Variables – Dissipative controller gains
  Diameters of structural members



- Objective Function – For parameter $0 \le \beta \le 1$,

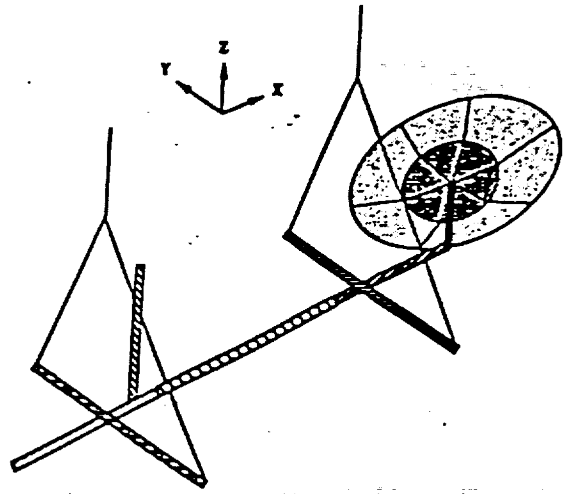
  Minimize $\left[\beta \cdot \text{Total Mass} + \dfrac{(1-\beta)}{\text{Controlled Performance}}\right]$

- Constraints
  – Structural member sizes and RMS pointing error at large antenna

CONVENTIONAL VS. INTEGRATED
(Dynamic Dissipative Controller)
RMS < 10 μrad

	Controlled Performance	Structural Mass	Actuator Mass	Total Mass
Initial Design	1.0	1.0	1.0	1.0
Control-optimized Design β=0.15	1.30	1.0	1.45	1.18
Integrated Design β=0.15	4.03	0.66	1.44	0.97

INTEGRATED DESIGN VALIDATION
PHASE-1 CEM



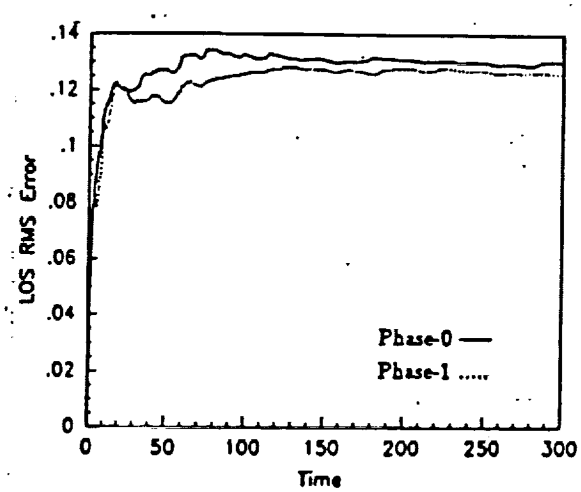
- OBJECTIVE: MINIMIZE THE AVERAGE CONTROL POWER WHILE MAINTAINING THE RMS LINE OF SIGHT (LOS) TO A SPECIFIED VALUE WITHOUT ANY INCREASE IN STRUCTURAL MASS (OVER PHASE-0 DESIGN).

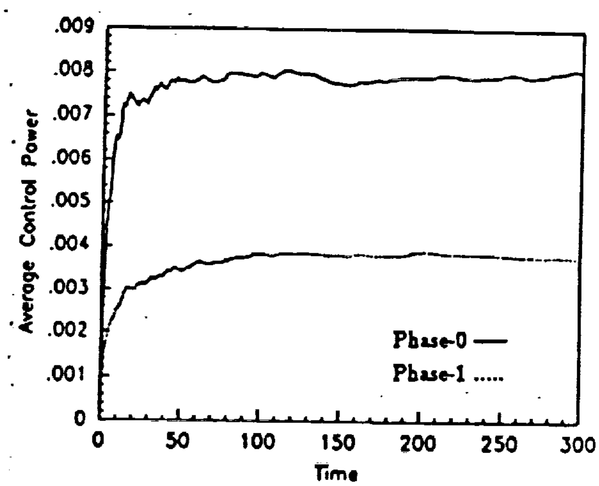
- DESIGN VARIABLES

  STRUCTURE - EFFECTIVE CROSS-SECTIONAL AREAS OF 21 LONGERONS, BATTENS, AND DIAGONALS

  CONTROL - ELEMENTS OF THE COMENSATOR AND GAIN MATRICES OF A DYNAMIC DISSIPATIVE CONTROLLER

SIMULATION RESULTS





JUSTIFICATION FOR ON-ORBIT CSI EXPERIMENTS

- DEVELOP UNDERSTANDING OF GRAVITY EFFECTS ON GROUND TESTING
  - Direct Gravity Effects: stiffness, modal coupling, damping
  - Indirect Gravity Effects via Suspension system dynamics: pendulous modes, local attachment loads, large angle articulation limitations, etc.

- QUANTIFY ACCURACY OF PREDICTIONS OF ON-ORBIT PERFORMANCE

- DEMONSTRATE NEW FLIGHT QUALIFICATION PROCEDURE
  - Dependent on on-orbit dynamic testing
  - Subsequent adjustment of controller parameters

CSIO FLIGHT EXPERIMENTS

- JITTER SUPPRESSION EXPERIMENT (JSX)
  - McDonnell Douglas Prime Contractor
  - Funded by OAET's In-Space Technology Experiments Program (In-STEP)

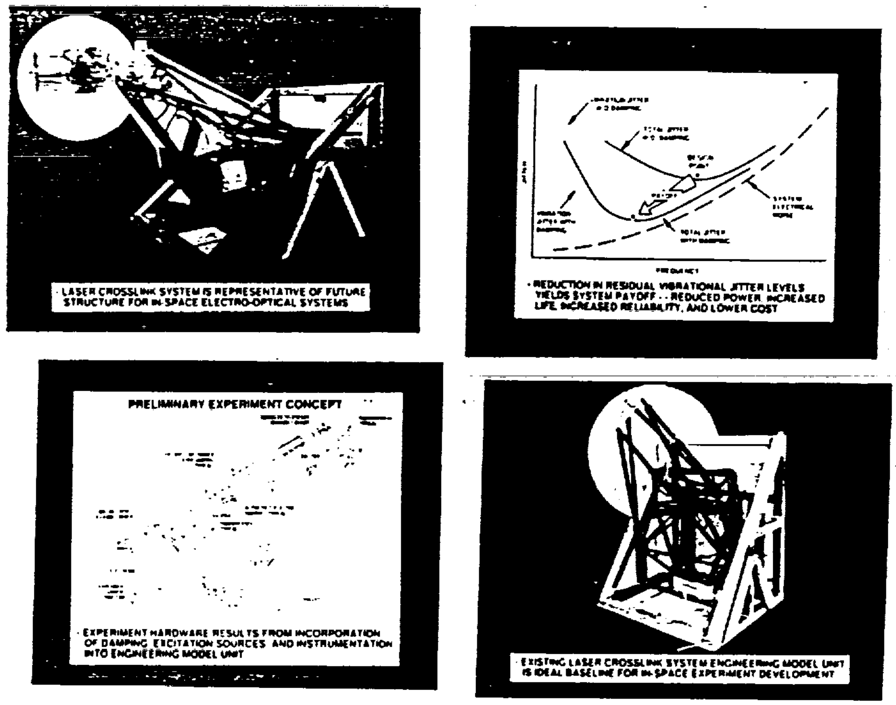
- MIDDECK ACTIVE CONTROL EXPERIMENT (MACE)
  - MIT Prime Contractor
  - Funded by In-STEP

- ADVANCED FREE-FLYER EXPERIMENT
  - LaRC/MSFC/JPL Conceptual Definition in Progress

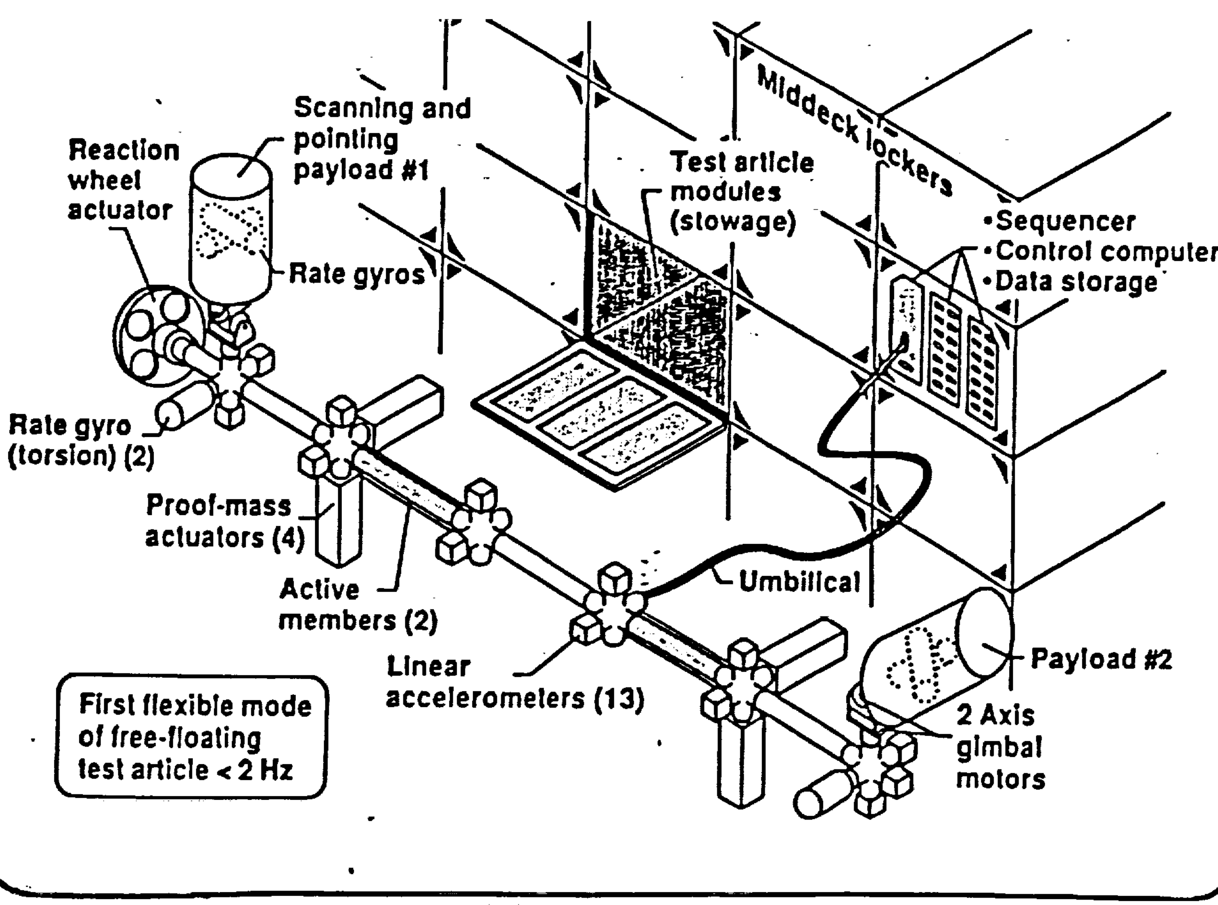
NASA OAST IN SPACE TECHNOLOGY EXPERIMENT

**JITTER SUPPRESSION
FOR
PRECISION SPACE STRUCTURES**

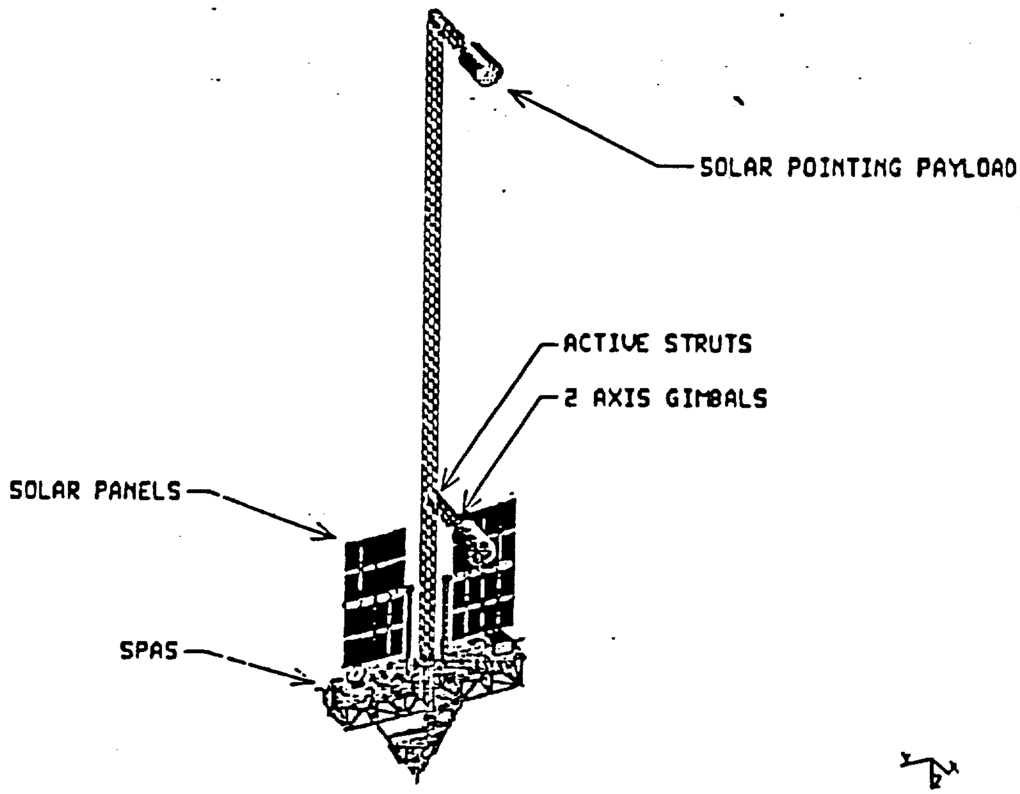
CONTRACT NAS1 18689



MIDDECK ACTIVE CONTROL EXPERIMENT (MACE)



CSI FREE FLYING EXPERIMENT



SUMMARY

- CONTROLS-STRUCTURES INTERACTION (CSI) IS A KEY ENABLING TECHNOLOGY FOR FUTURE NASA SPACECRAFT
- PROPER IMPLEMENTATION OF CSI TECHNOLOGY OFFERS THE POTENTIAL FOR SIGNIFICANT IMPROVEMENTS IN CAPABILITY
- CSI IS EFFECTIVELY A NEW DISCIPLINE WHICH ENCOMPASSES AND INTEGRALLY MERGES STRUCTURES AND CONTROLS
- NASA HAS EMBARKED ON A MAJOR MULTI-CENTER EFFORT TO DEVELOP THIS TECHNOLOGY FOR PRACTICAL APPLICATION TO SPACECRAFT

INTEGRATED TECHNOLOGY PLAN
FOR THE CIVIL SPACE PROGRAM

N93-71841

SPACE ENVIRONMENTAL EFFECTS, MATERIALS AND NDE/NDI PRESENTATION TO SSTAC/ARTS REVIEW COMMITTEE

57-81

157517

p. 13

Samuel L. Venneri
Director
Materials and Structures Division

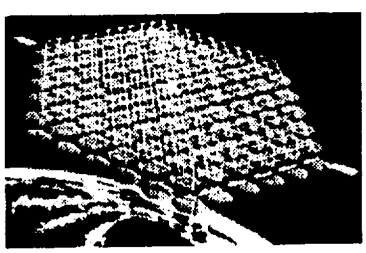
JUNE 26, 1991

OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON, DC 20546

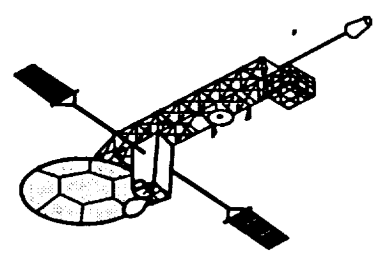
TECHNOLOGY DRIVERS . OR SPACE MATERIALS

Space Durable Polymers



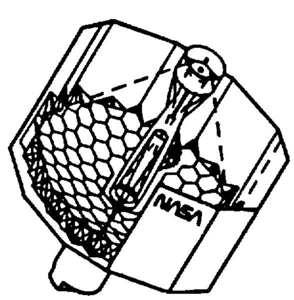
- Lightweight stable materials needed to fulfill future NASA missions
- Mars mission, lunar base, global change initiative

High Performance Composites

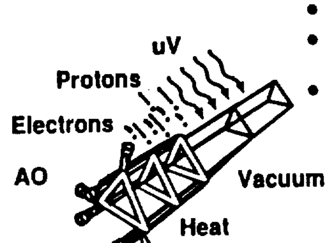


- Stable platforms & instrument supports
- Large lightweight reflectors

Precision Reflector Panels



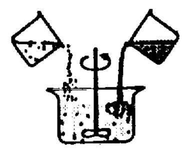
Long-term qualification



- LEO & GEO orbits
- Life characterization methodology
- Environmental effects data base

SPACE DURABLE POLYMERS

Matrix Resins

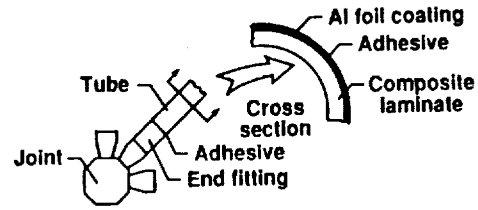


Resin development

- Inherent stability through design/synthesis
- Favorable strength/weight ratio
- Prepregging/processing

Adhesives

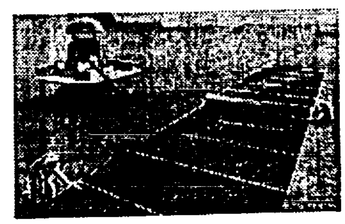
- Space durable
- Low outgassing



Films/Coatings

- Low color, low dielectric polymers
- Applications as reflectors, optical devices, solar arrays & antennaes
- Environmentally protective coatings

Rigidizable Polymers



- Large structures fabricated in space
- Fewer launches required for construction
- Applications include lunar habitat vehicle assembly/storage area

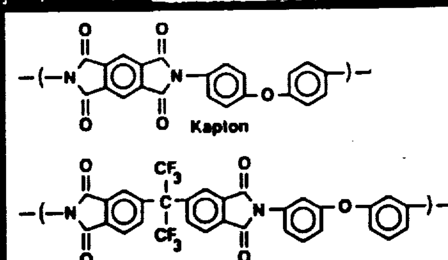
SIMULATED SPACE ENVIRONMENTAL EFFECTS

Electron beam and ultraviolet radiation

Polymer films

Objective: To develop electron ultraviolet radiation resistant, low color polymer films for space applications

Approach: Prepare polymides containing oxygen bridges and meta catenation, expose and evaluate optical transmission

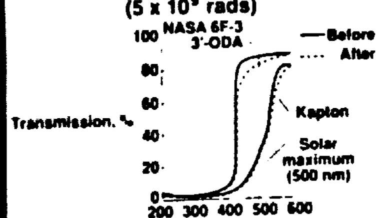


Kapton

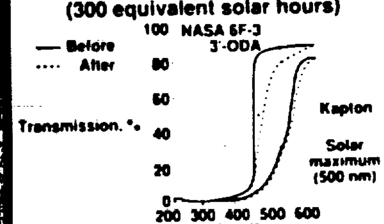
NASA 6F-3,3'-ODA

Ultraviolet-visible spectra

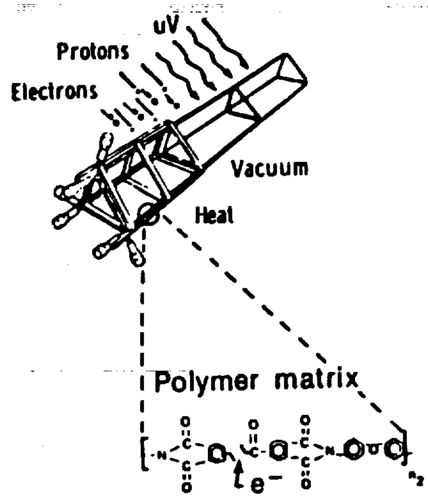
ELECTRON BEAM EXPOSURE
(5×10^9 rads)

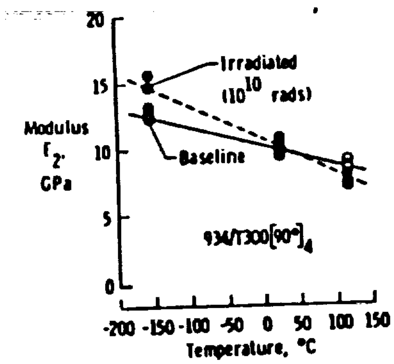


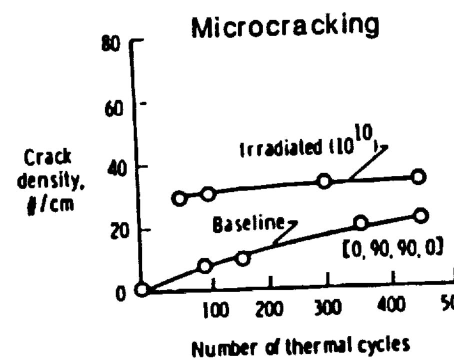
ULTRAVIOLET EXPOSURE
(300 equivalent solar hours)



SPACE RADIATION EFFECTS ON POLYMER MATRIX COMPOSITES





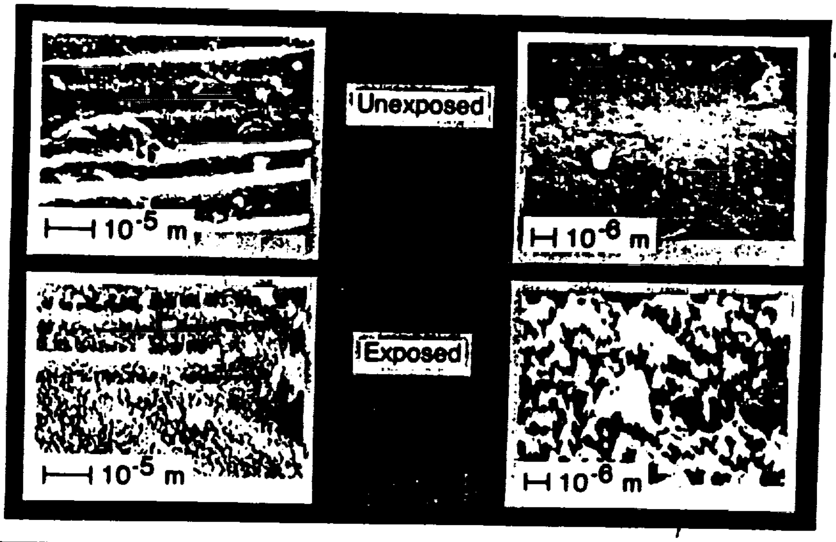


- Radiation effects:
  - Chain scission and crosslinking in polymers
  - Property changes
  - Microcracking during thermal cycling

CURRENT/ADVANCED COATINGS FOR SPACECRAFT

COATING TYPE / SUBSTRATE	COATING COMPOSITION / DESIGNATION	CONCERNS
ANODIZED/ ALUMINUM ALLOYS	CHROMIC ACID ANODIZE SULFURIC ACID ANODIZE OXALIC ACID ANODIZE	THERMOMECHANICAL STABILITY
ANODIZED Al FOIL/ GRAPHITE-EPOXY COMPOSITES	CHROMIC ACID ANODIZE ON A-1100 FOIL	THERMOMECHANICAL STABILITY ADHESIVE STABILITY
WHITE PAINTS/ Al, COMPOSITES	ZINC OXIDE-SILICATE / Z-93 ZINC OXIDE-SILICONE / S13GLO ZINC ORTHOTITINATE-SILICATE / YB-71 CHEMGLAZE, A-276	THERMOMECHANICAL STABILITY ATOMIC OXYGEN
BLACK PAINTS/ Al, COMPOSITES	CHEMGLAZE, Z-306 IITRI, D-111	THERMO-MECH STAB. ATOMIC OXYGEN
THIN FILMS (<5000A)/ OPTICS, RADIATORS, SOLAR VOLTAICS	SILICON DIOXIDE ON ORGANICS ALUMINUM LEAD-TIN	ATOMIC OXYGEN DEFECT CONTENT DEBRIS IMPACT

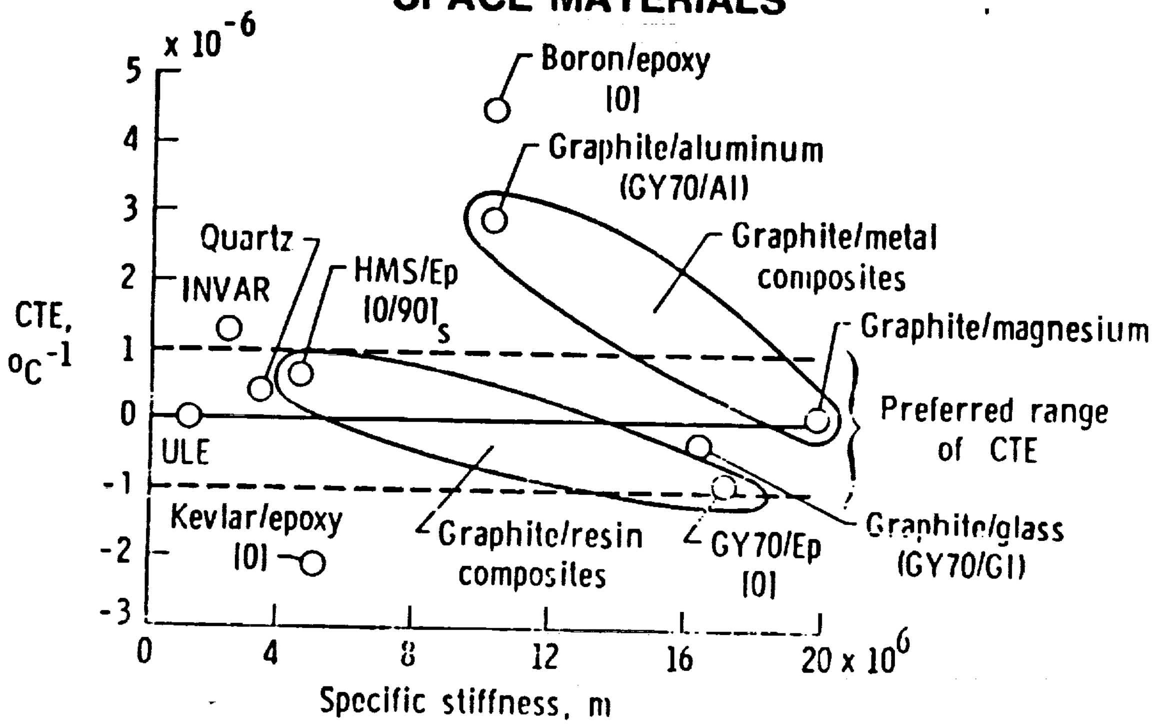
EFFECT OF AT(IIC OXYGEN ON A GRAPHITE-EPOXY COMPOSITE



	REACTION EFFICIENCY (CM^3/ATOM)
GRAPHITE/EPOXY	2.4×10^{-24}
KAPTON	3.0×10^{-24}
TEFLON	$< 0.05 \times 10^{-24}$
ALUMINUM AND CERAMICS	$< 0.001 \times 10^{-24}$

RM 502.1

HIGH STIFFNESS LOW THERMAL EXPANSION SPACE MATERIALS



LONG DURATION EXPOSURE FACILITY

- Launched - April 1984 Retrieval - January 1990
- 57 Technology, Science, and Applications Experiments
  (More than 10,000 test specimens)
- Participants
  - P.I.'s: >200
  - Industry: 33
  - NASA Centers: 7
  - Countries: 9
  - Universities: 21
  - DOD Labs: 9
  - Special Investigation Groups (Approx. 60 participants)
    (Materials, Systems, Meteoroid/Debris, & Radiation)

THE LDEF EO ENVIRONMENT

- ATOMIC OXYGEN
- UV RADIATION
- PARTICULATE RADIATION
  p^+, e^-, COSMIC
- METEROID AND DEBRIS
- VACUUM
- THERMAL CYCLING
- CONTAMINATION
- SYNERGISTIC EFFECTS

PRELIMINARY EXPOSURE CONDITIONS

- Atomic oxygen
  8.3×10^{21} atoms/cm^2
- UV radiation
  100-400 nm; 16,000 hrs
- Particulate radiation
  e^- and p^+: 2.5×10^5 rad surface fluence
  Cosmic: <10 rads
- Micrometeroid and debris
  734 impact craters <0.5 mm
  74 impact craters >0.5 mm
- Vacuum
  1.33×10^{-4} - 1.33×10^{-5} N/m^2 (10^{-6} - 10^{-7} torr)
- Thermal cycles
  ~34,000 cycles: -29 to 71°C, ±11°
  (-20 to 160°F, ±20°)
- Altitude
  4.72×10^5 - 3.33×10^5 m (255-180 nautical miles)
- Orbital inclination
  28.5°

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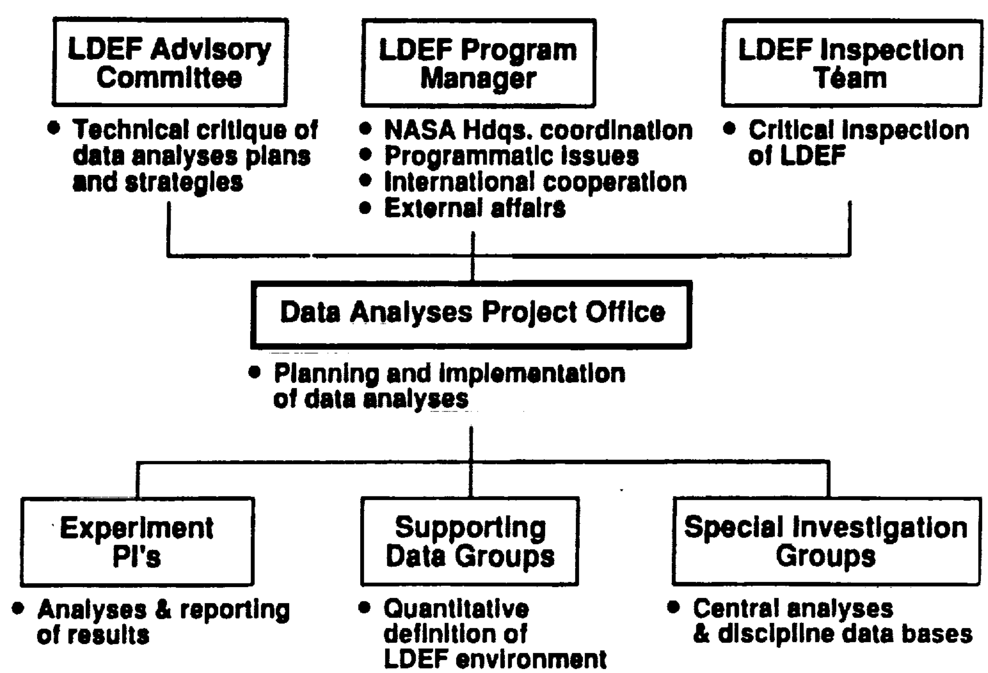
NASA FORM 1598 APR 87

LDEF DATA ANALYSIS GROUPS AND FUNCTIONAL RESPONSIBILITIES



LDEF Special Investigation Groups (SIG)

Special Investigation Groups

Materials — Bland A. Stein
- NASA - 13
- DOD - 2
- SDIO
- Aerospace - 2
- Boeing
- ESTEC
- CERT
- N. of Toronto

Induced Radiation — Tom Parnell
- NASA - 5
- DOD - 2
- SDIO
- U. of Berkeley
- Lawrence Berkeley Labs
- Brookhaven Nat'l Labs
- Mississippi State U.
- Dublin Institute for Advanced Studies - 2
- Science Applications International Corp.
- U. of Siegen
- Royal Aerospace Establishment

Meteoroid and Space Debris — William H. Kinard
- NASA - 11
- DOD
- SDIO
- U. of Washington
- Aerospace Corp.
- POD Associates, Inc.
- U. of Kent at Canterbury
- Washington U. - 2
- S-Cubed
- Lockheed
- CERT/ONERA-DERTS

Environmental Effects on Systems — James B. Mason
- NASA - 8
- DOD
- SDIO
- Aerospace - 2
- CNES
- Boeing
- EER

LDEF INSPECTION TEAM

LDEF RETRIEVAL OBSERVATIONS FROM DOWNLINK VIDEO, IN-SPACE PHOTOGRAPHS, AND INITIAL KSC OBSERVATIONS

<u>GENERAL</u>

- NO STRUCTURAL DAMAGE
- NO UNANTICIPATED PHENOMENA
- DAMAGE TO THIN FILMS, COATINGS, AND THERMAL BLANKET MATERIALS ON EXPERIMENT TRAYS, PREDOMINANTLY ON:
  - LEADING EDGE
  - SPACE END
- FLOATING DEBRIS VISIBLE NEAR LDEF, ESPECIALLY AFTER GRAPPLE
- MINIMAL DEBRIS IN CARGO BAY; SOLAR CELL MODULE ONLY LARGE PIECE OF DEBRIS FOUND
- LOCALIZED CONTAMINATION ON LDEF SURFACES IN SEVERAL AREAS

LDEF INSPECTION TEAM

LDEF RETRIEVAL OBSERVATIONS FROM DOWNLINK VIDEO, IN-SPACE PHOTOGRAPHS, AND INITIAL KSC OBSERVATIONS (CONCLUDED)

ATOMIC OXYGEN EFFECTS

- SIGNIFICANT ATOMIC OXYGEN DEGRADATION OBSERVED ON MOST LEADING EDGE EXPERIMENTS.
- MORE THAN 0.005-INCH DEGRADATION OF KAPTON AND MYLAR FILMS ON LEADING EDGE EXPERIMENTS.
- SURFACES OF SILVER/TEFLON THERMAL BLANKETS ON LEADING EDGE TURNED "MILKY" WHITE.
- THERMAL CONTROL PAINT "TARGET SPOTS" REMAINED WHITE ON ENTIRE LEADING FACE OF LDEF.

ULTRAVIOLET RADIATION EFFECTS

- THERMAL CONTROL PAINT TARGET SPOTS DISCOLORED ON TRAILING FACE, EARTH END, AND SPACE END OF LDEF.

INDUCED RADIATION EFFECTS

- INDUCED RADIATION SURVEYS SHOW MEASUREABLE RADIOACTIVE ACTIVITY.
- NO THREATS TO HUMAN HEALTH.

LDEF INSPECTION TEAM

LDEF RETRIEVAL OBSERVATIONS FROM DOWNLINK VIDEO, IN-SPACE PHOTOGRAPHS, AND INITIAL KSC OBSERVATIONS (CONTINUED)

MECHANISMS AND SYSTEMS

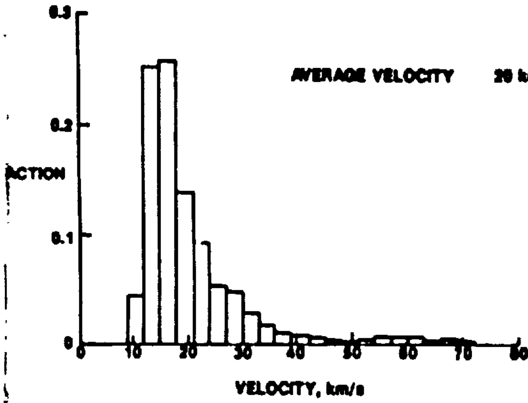
- FIVE EXPERIMENT EXPOSURE CONTROL CANISTERS (EECCs) ON LDEF
  - FOUR CLOSED
  - ONE OPEN (PROBABLY CLOSED AND REOPENED)
- MSFC SPECTROPHOTOMETER CAROUSEL EXPERIMENT APPEARS TO HAVE FUNCTIONED CORRECTLY.

MICROMETEOROID AND DEBRIS EFFECTS

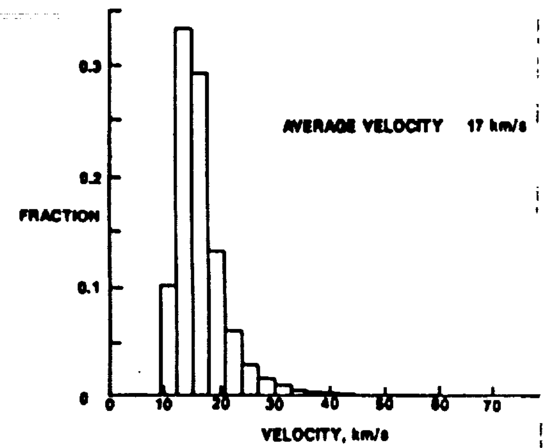
- SIGNIFICANT MICROMETEOROID AND DEBRIS IMPACTS OBSERVED ON EXPERIMENT TRAYS; IMPACTS GENERALLY CONSISTENT WITH EXPECTATIONS.
- NO LARGE, CATASTROPHIC IMPACT EVENTS DETECTED.
- MORE MICROMETEOROID/DEBRIS DAMAGE APPARENT ON LEADING EDGE THAN ON TRAILING EDGE.
- IMPACTS ALSO OBSERVED ON LDEF STRUCTURE.

METEOROID & DEBRIS VELOCITY DISTRIBUTION

SP-8013

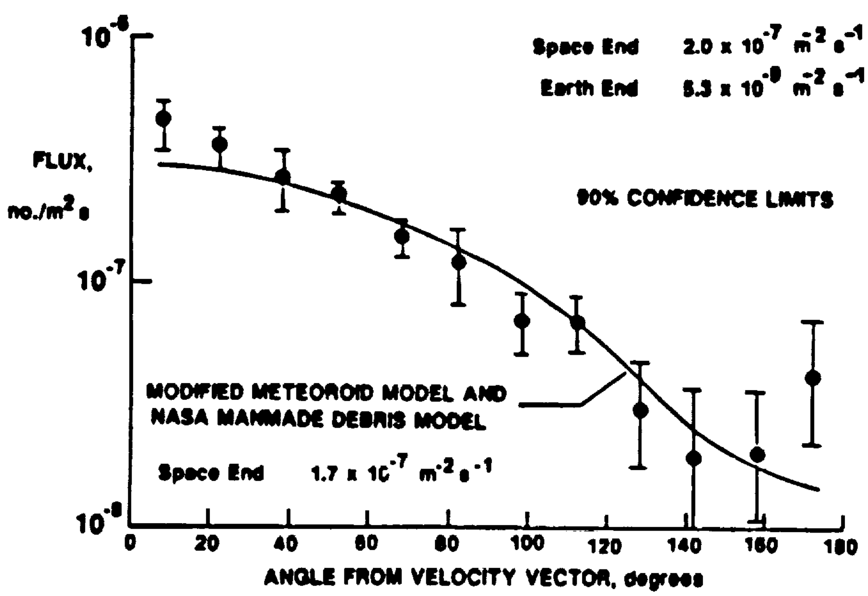


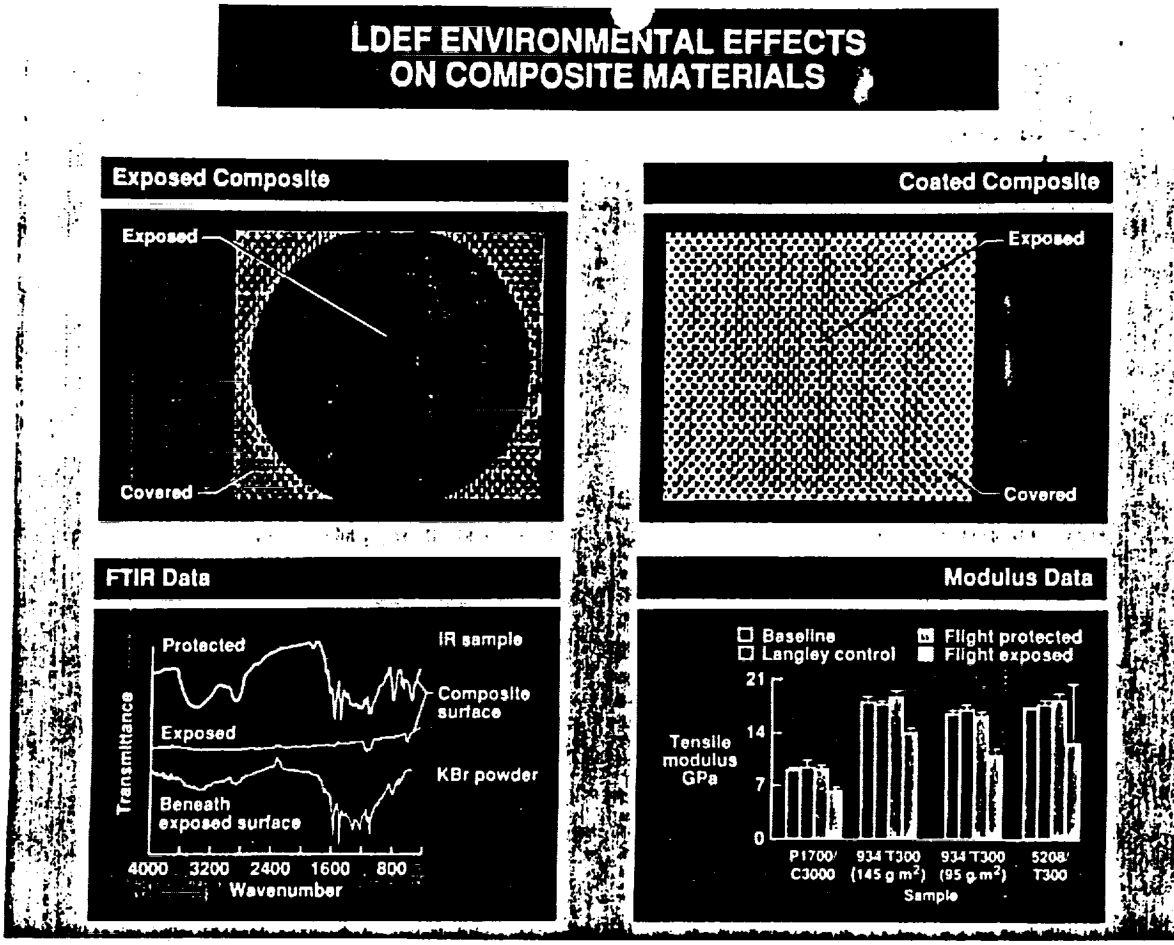
ERICKSON



FLUX OF LARGE CRAT .RS IN ALUMINUM

≥ 0.5 MM (LIP DIAMETER)





LDEF SYSTEMS FLIGHT HARDWARE

- Mechanical/Structural Systems and Components
  - Viscous damper/grapple
  - Motors
  - Valves
  - Lubricants
  - Seals
  - Etc.

- Electrical/Electronic Systems and Components
  - Data and initiate systems
  - Tape recorders
  - Batteries
  - PC boards/solder/conformal coatings
  - Etc.

- Thermal Control Systems and Components
  - Heat pipes
  - Thermal isolators
  - MLI
  - Painted/coated thermal control surfaces
  - Etc.

- Optical Systems and Components
  - Glasses
  - Fiber optics
  - Optical detectors
  - Filters
  - Optical sources
  - Etc.

SPACE ENVIRONMENTAL EFFECTS

Scope

- Space Environment Simulations
  - e^-, p^+, UV
  - Atomic oxygen
  - Micrometeoroid and debris
  - Thermal cycling
  - Contamination

- Flight Experiments
  - LDEF
  - EOIM-3
  - EISG - Spacecraft glow

- Development of Space Durable Materials
  - Polymer
  - Coatings
  - Composites

- Space Component Fabrication Technology
  - Precision panels
  - High modulus tubes
  - Blankets
  - Bumper shields

RESEARCH IN SPACE ENVIRONMENTAL EFFECTS

OAET

ENVIRONMENTAL FACTORS	SPACE ENVIRONMENT DEFINED	GROUND-BASED VALIDATION METHODOLOGY	GROUND-BASED FACILITY DEVELOPMENT	FLIGHT TESTING	LIFE PREDICTION
IR/THERMAL	MATURE	MATURE	ONGOING	ONGOING	ONGOING
UV	MATURE	MATURE	ONGOING	ONGOING	ONGOING
PROTONS	ONGOING	INFANCY	INFANCY	INFANCY	INFANCY
ELECTRONS	ONGOING	ONGOING	INFANCY	INFANCY	INFANCY
ATOMIC OXYGEN	ONGOING	ONGOING	INFANCY	ONGOING	INFANCY
DEBRIS	ONGOING	ONGOING	INFANCY	INFANCY	INFANCY
CONTAMINATION	ONGOING	ONGOING	INFANCY	ONGOING	ONGOING
PLASMA	ONGOING	INFANCY	INFANCY	INFANCY	INFANCY
COMBINED EFFECTS	ONGOING	INFANCY	INFANCY	ONGOING	INFANCY

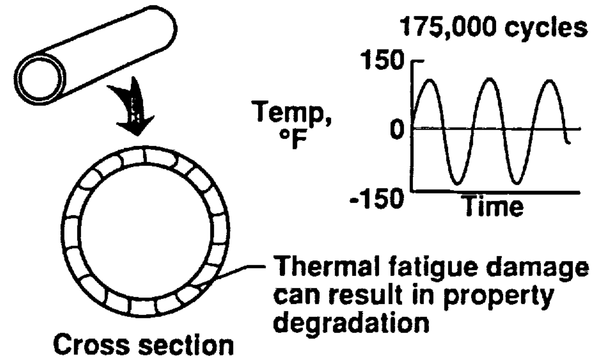
MATURE ONGOING INFANCY

LONG-TERM QUALIFICATION

"National Lab" Stature Facilities

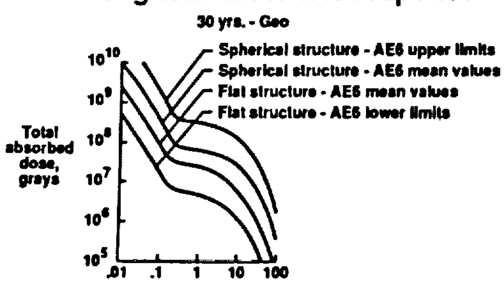
- Combined Exposures (e^-, p^+, UV, thermal cycling)
- In-situ characterization
  - Optical properties
  - Species identification
  - Mechanical properties
  - Mass loss

Benchmark Experiments

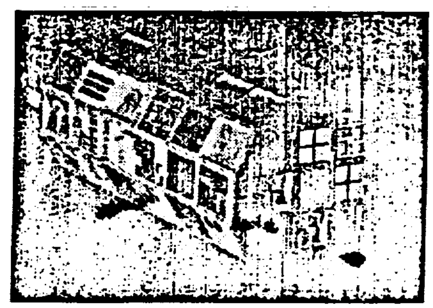


Environmental Aging Models

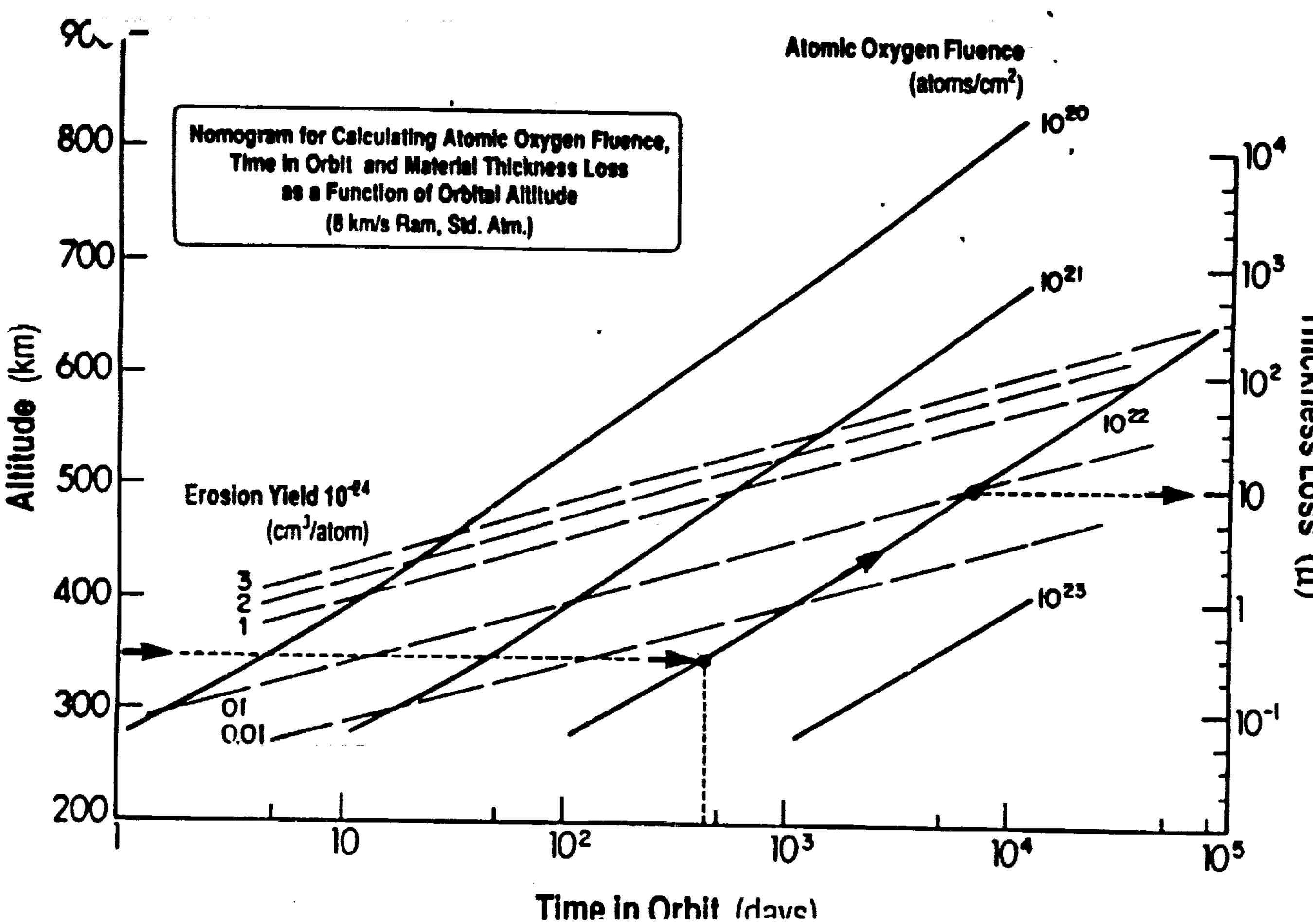
- Environmental parameters
- Long-term materials response



Flight Experiment Verification



- LDEF
- EOIM 3



NASA SPACE MATERIALS DEVELOPMENT AND APPLICATIONS

- New Materials Development
  - Ultra high performance composites
  - Advanced polymers and coatings
  - Computational materials
  - Smart materials

- Focused Technology Applications
  - Platforms
  - Reflectors
  - Optical benches

- Space Environmental Effects
  - Ground based simulations
  - Flight experiments
  - Life prediction methodology

NASA SPACE MATERIALS DEVELOPMENT AND APPLICATIONS

- Key element of OAET space program under R&T base, platforms, science and exploration

- Structure to support NASA and industry long-term space applications programs

- Coordinate with DOD/SDIO programs

- Space envrionmental effects is a subelement

- Flight experiments including LDEF are a subelement under space environmental effects

INTEGRATED TECHNOLOGY PLAN
FOR THE CIVIL SPACE PROGRAM

N93-71842

STRUCTURES TECHNOLOGY PROJECT SUMMARY

EARTH ORBITING PLATFORMS PROGRAM AREA
OF THE
SPACE PLATFORMS TECHNOLOGY PROGRAM

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JUNE 26, 1991

OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON, DC 20546

SPACE PLATFORMS TECHNOLOGY -- EARTH-ORBTING PLATFORMS

STRUCTURES

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OBJECTIVES

Develop component and system level structural concepts and design methods to enable in-space construction and deployment of large platform structures in LEO and GEO including:

- Primary platform structures
- Reflectors and antenna
- Habitat and storage modules

SCHEDULE

Demonstrate concepts for precision deployable antenna and erectable reflector - FY 1994

Demonstrate erectable/deployable adaptive platform/antenna structural concept - FY 1996

RESOURCES ($M)

FY 1993	2.5
FY 1994	3.0
FY 1995	3.0
FY 1996	3.0
FY 1997	3.0

PARTICIPANTS

Langley Research Center (Lead)

Jet Propulsion Center

STRUCTURES

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TECHNOLOGY NEEDS

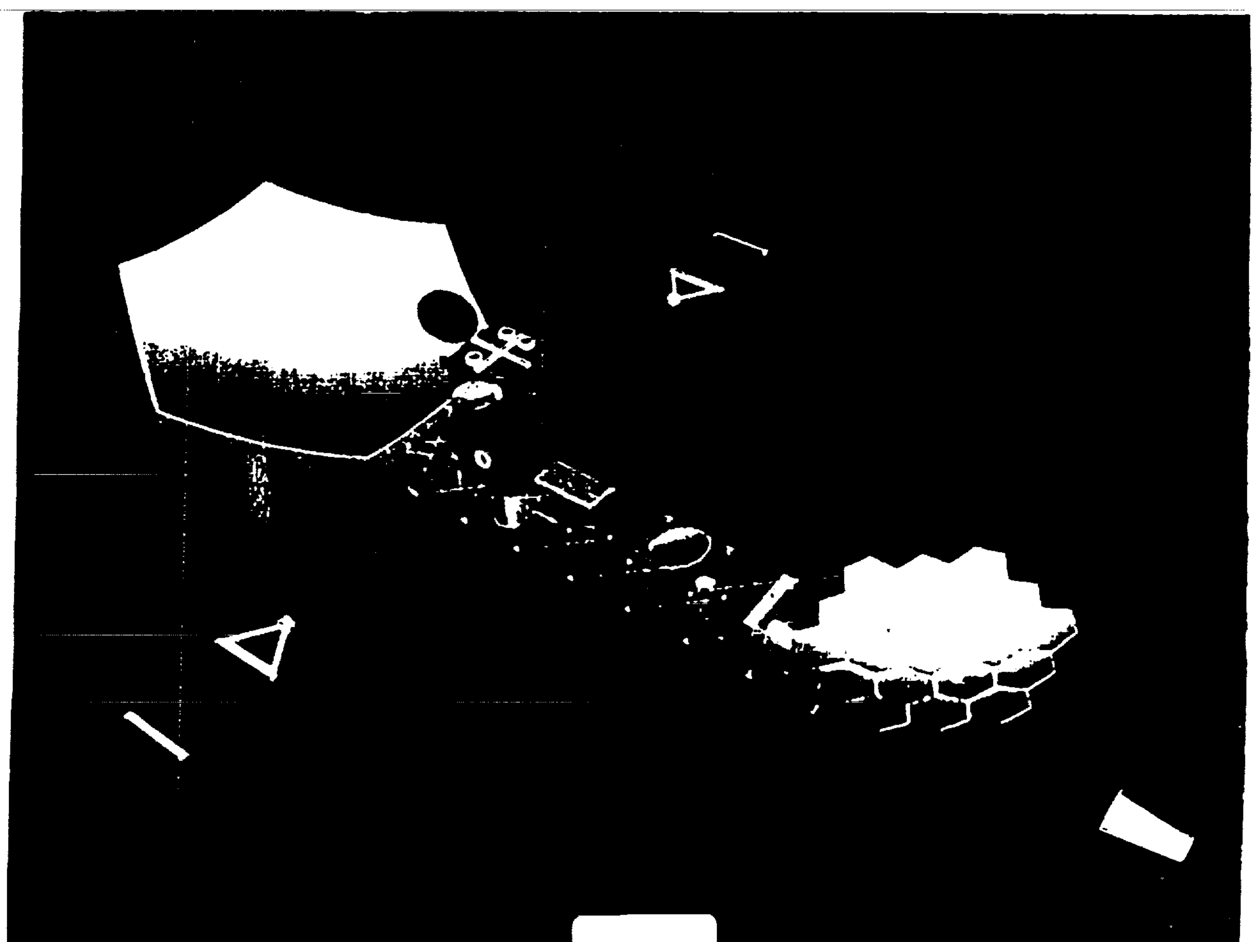
Spacecraft structures and structural components which can be constructed or deployed on-orbit to sizes and shapes not limited by launch vehicle constraints

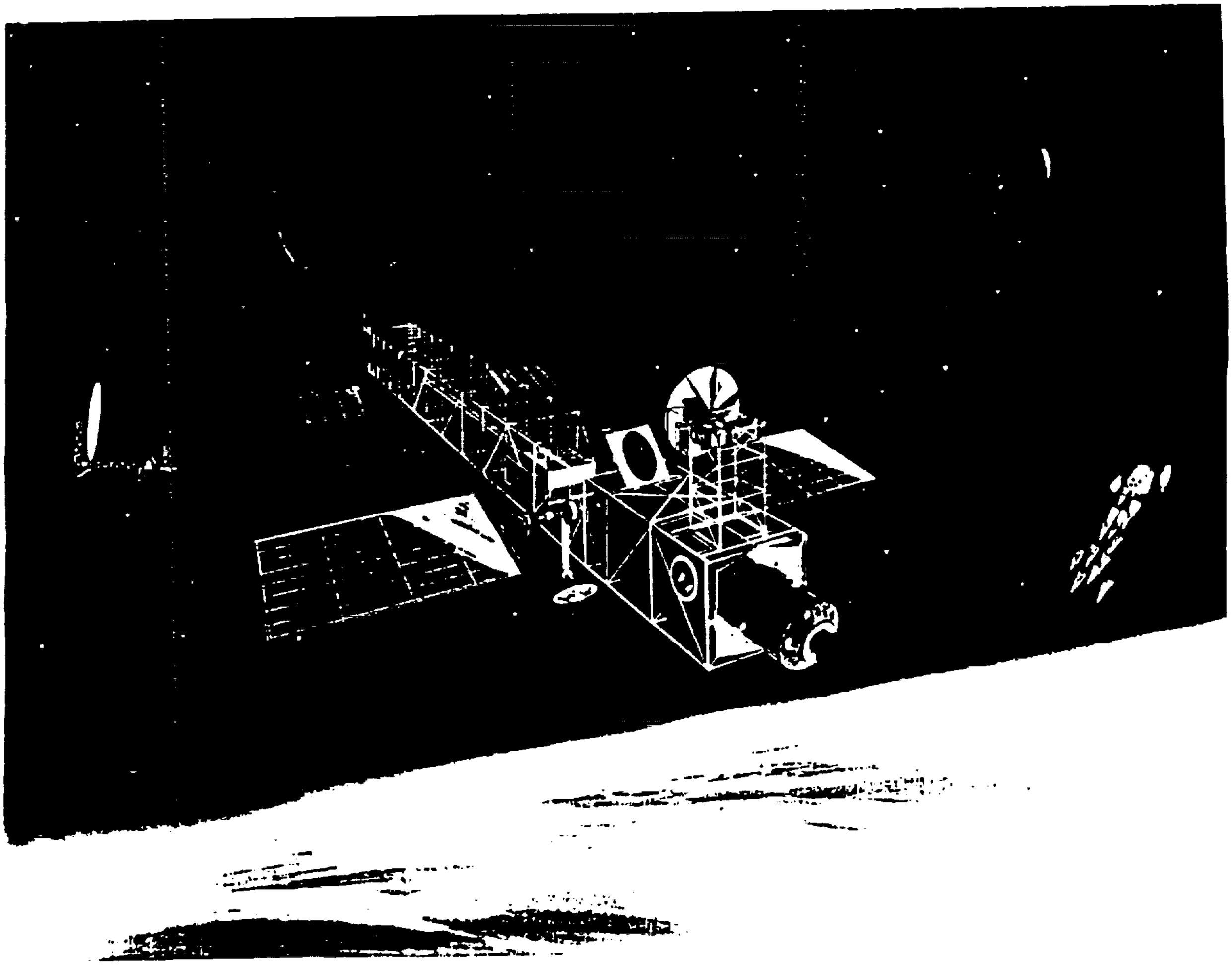
Antenna/radiometer and support structure concepts to support develoment of large geosynchronous orbit earth observing platforms

- Erectable/deployable platform truss structures 10-m to 50-m across
  - Fixed geometry and configurable beam truss structures to carry multiple large distributed payloads
  - Natural frequencies above about 10 Hz to enhance structural control and minimize payload dynamic interactions
- Erectable/deployable precision surfaces for radiometers and antenna
  - Diameters up to 40-m with sub-millimeter surface precision
  - Diameters up to 5-m with surface precision of several microns

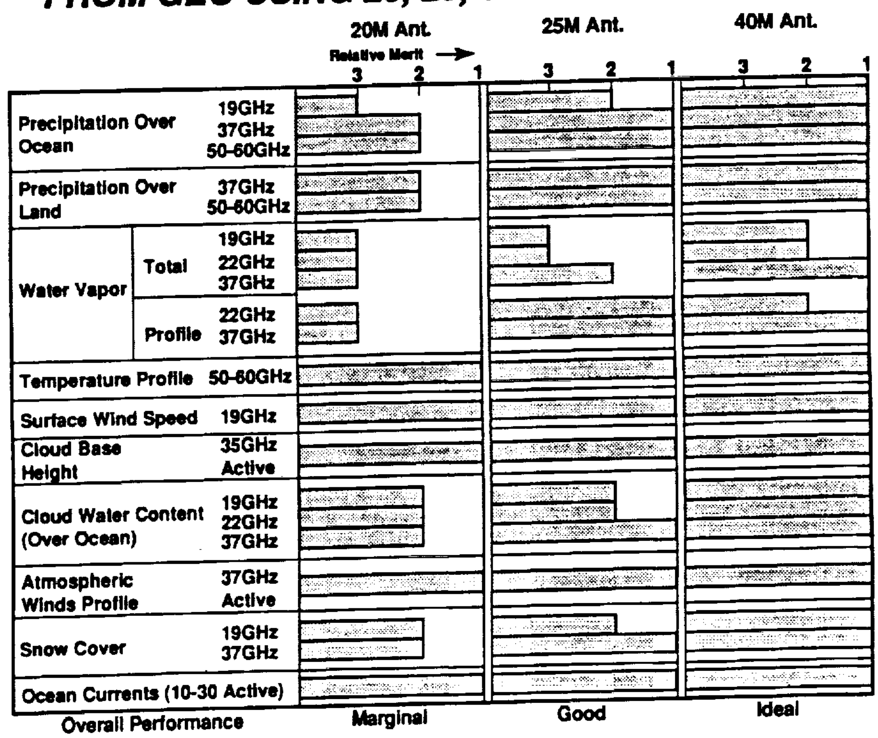
Evolutionary space station structures to support lunar SEI operations

- Advanced lightweight volumetric structures for manned platforms
  - Rigid and flexible (inflatable) shell structures for habitat modules
  - Erectable/deployable enclosures to provide environmental protection in LEO





RANKING VALUE OF MILLIMETER-WAVE OBSERVABLES FROM GEO USING 20, 25, & 40-M APERTURES



STRUCTURES

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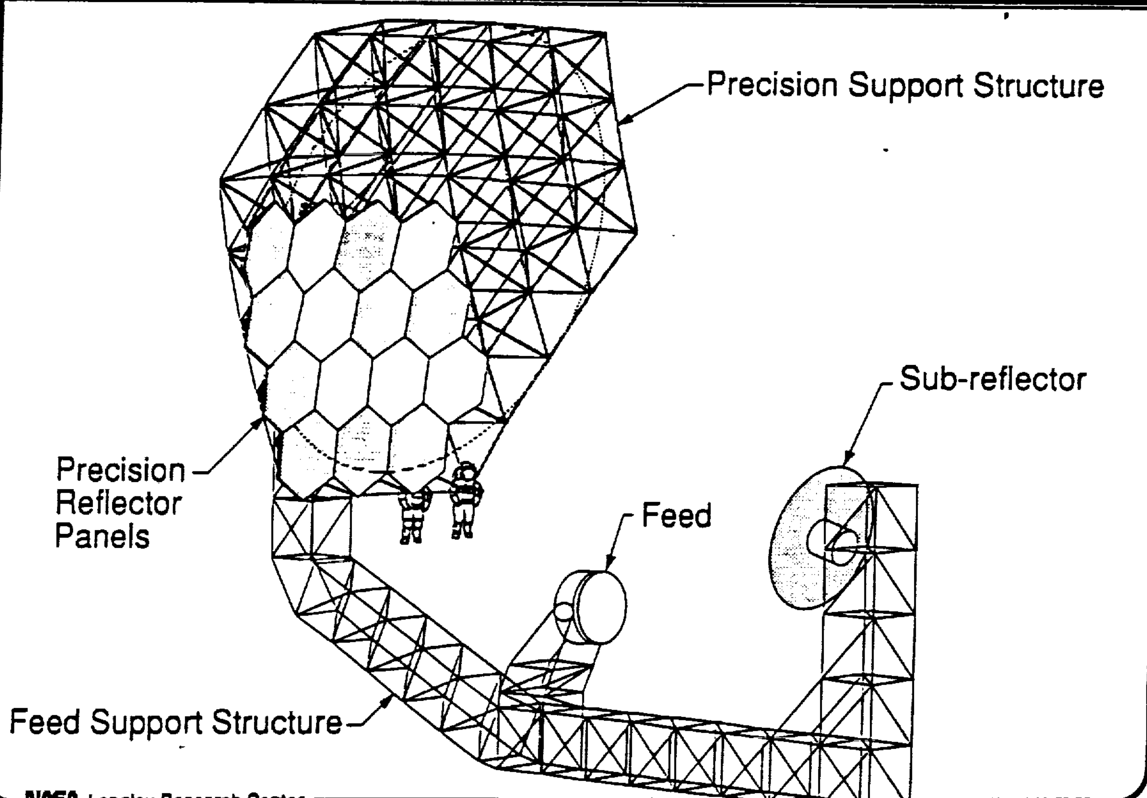
CURRENT PROGRAM

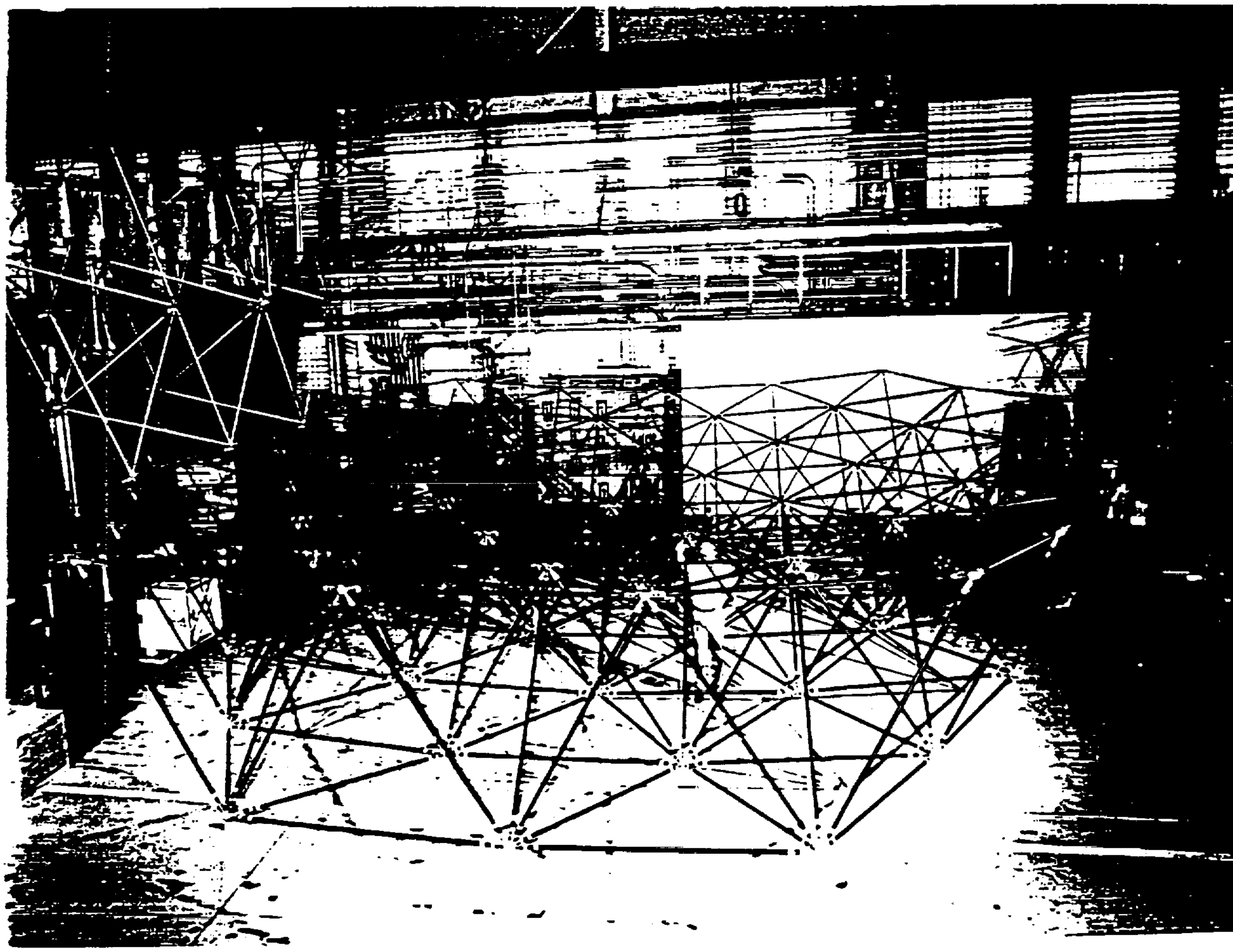
No focused technology program dedicated to platform structures

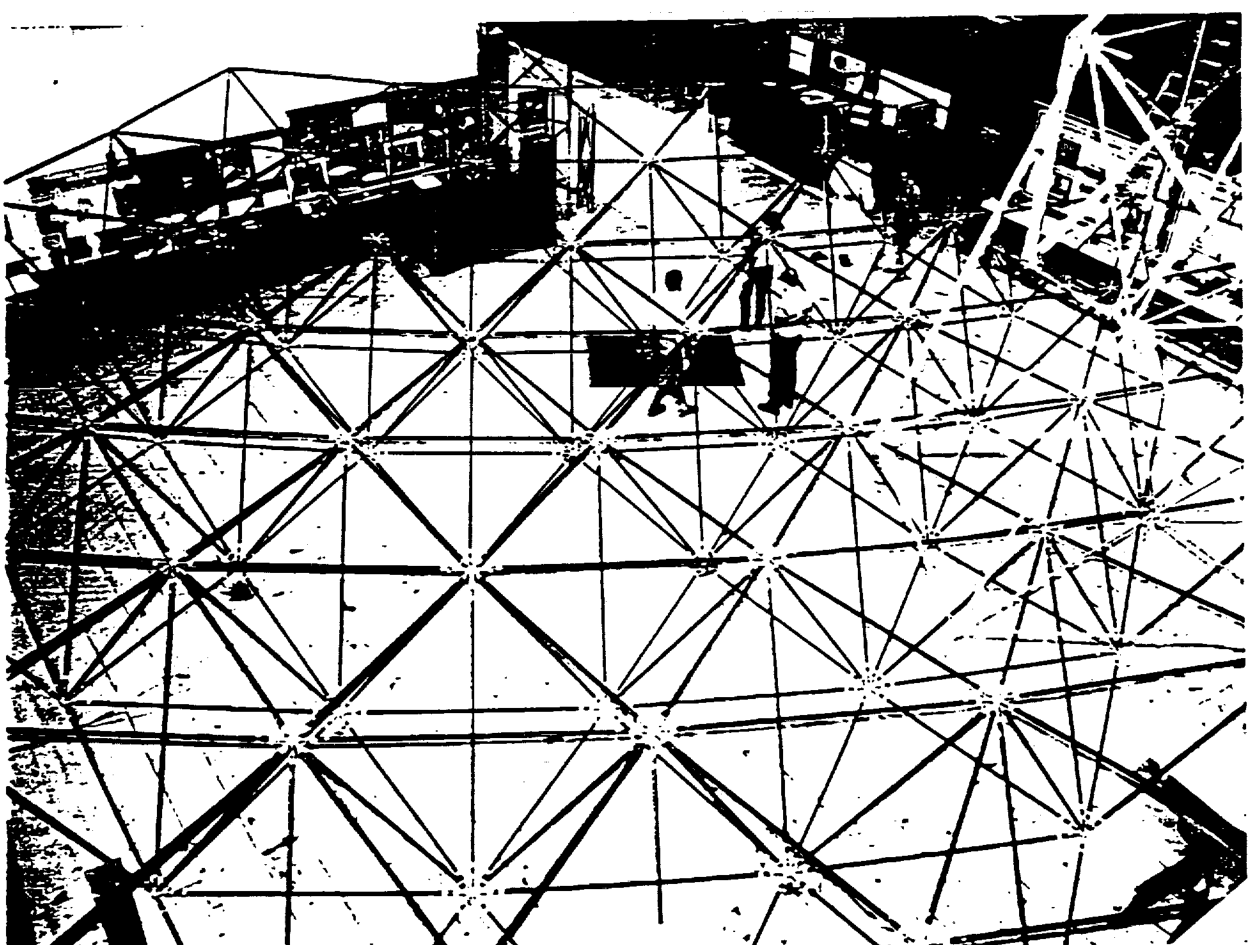
RELATED OAET STRUCTURES PROGRAMS

- Materials and Structures Base R&T
  - Erectable concepts for large antenna
  - Automated construction of truss structures
  - Development of structural optimization methods for truss structures and integrated thermal-structural-electromagnetic analyses
  - Developmant of space durable materials
  - Development of lightweight 2m reflector panels and attachments
- Precision Segmented Reflector Program (part of CSTI)
  - Development of a concept for a precision erectable back-up structure for a large submillimeter telescope
  - On-orbit constructability to be demonstrated by a 14m truss in the MSFC neutral buoyancy facility
- In-Space Assembly and Construction (originally part of Pathfinder)
  - Development of a large space crane concept
  - Development of construction methods for large space vehicles

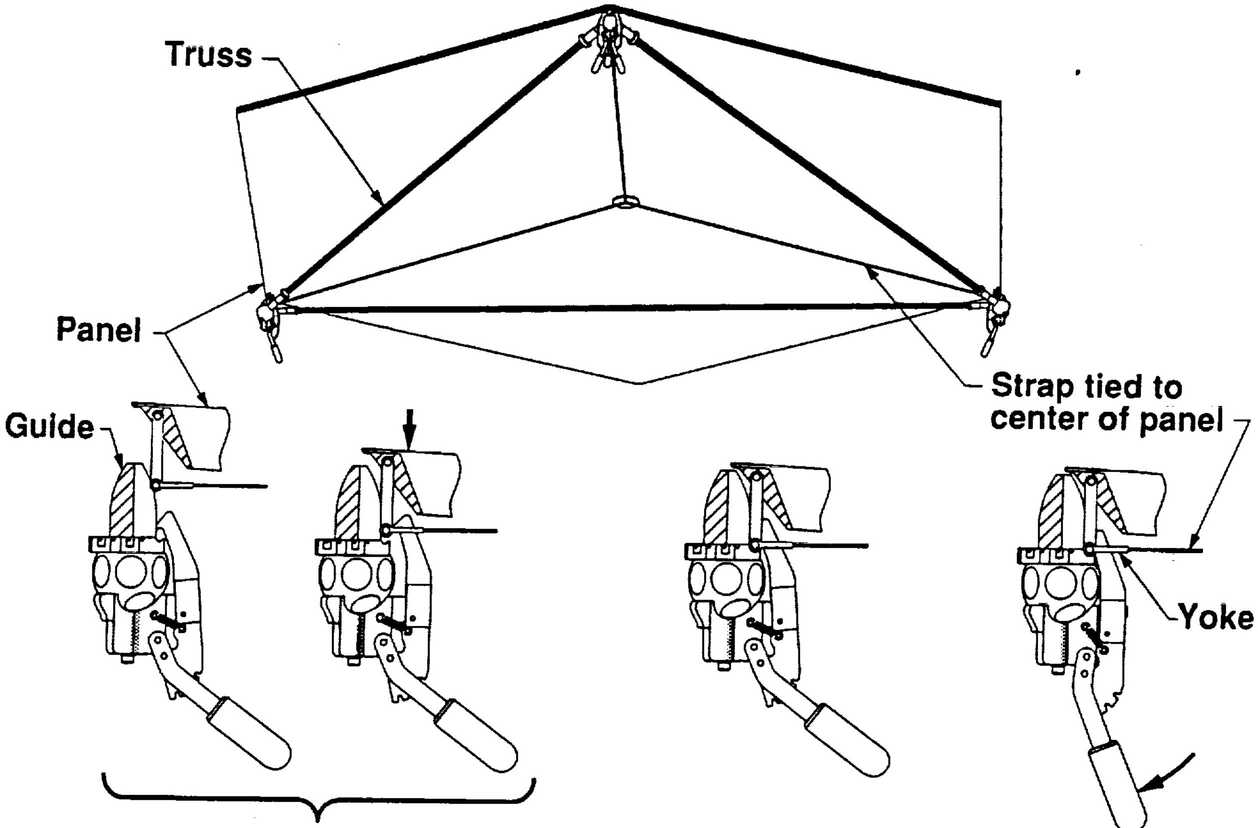
ANALYSIS & DESIGN CAPABILITY DEVELOPED FOR OFFSET FEED-ANTENNA TRUSS STRUCTURE



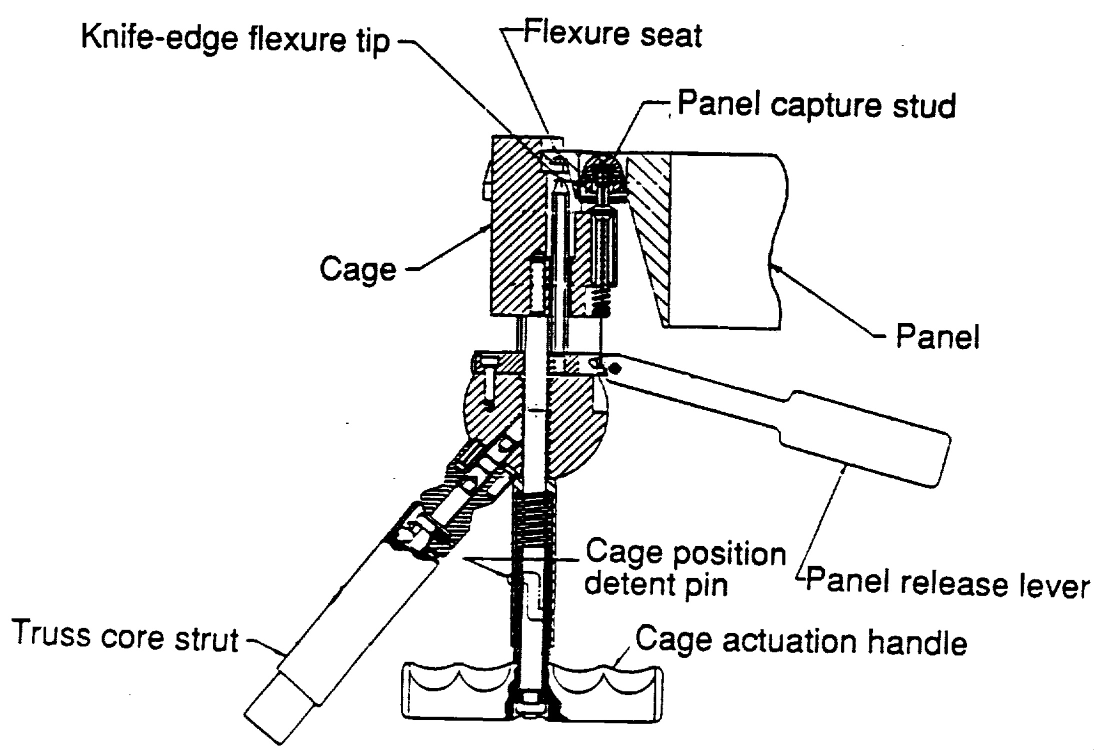




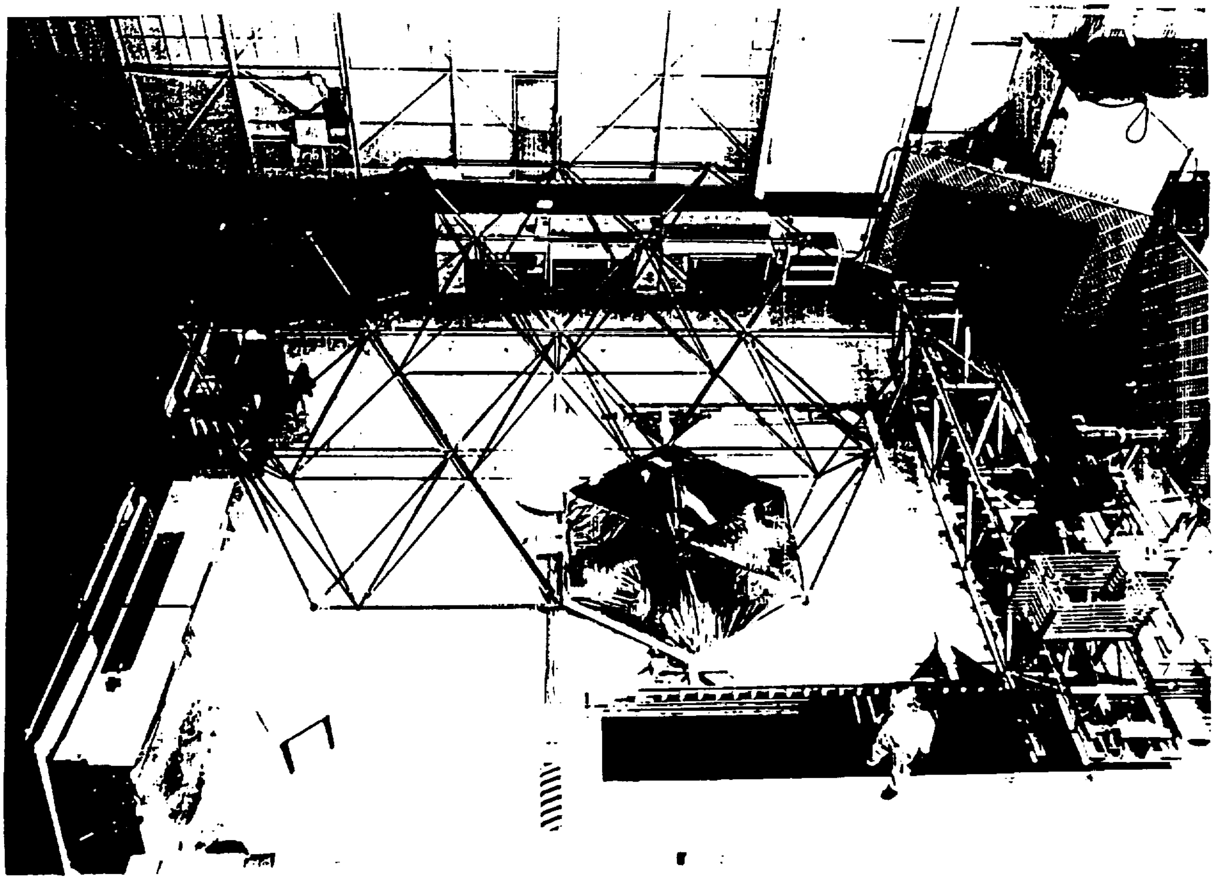
LaRC PANEL ATTACHMENT CONCEPT



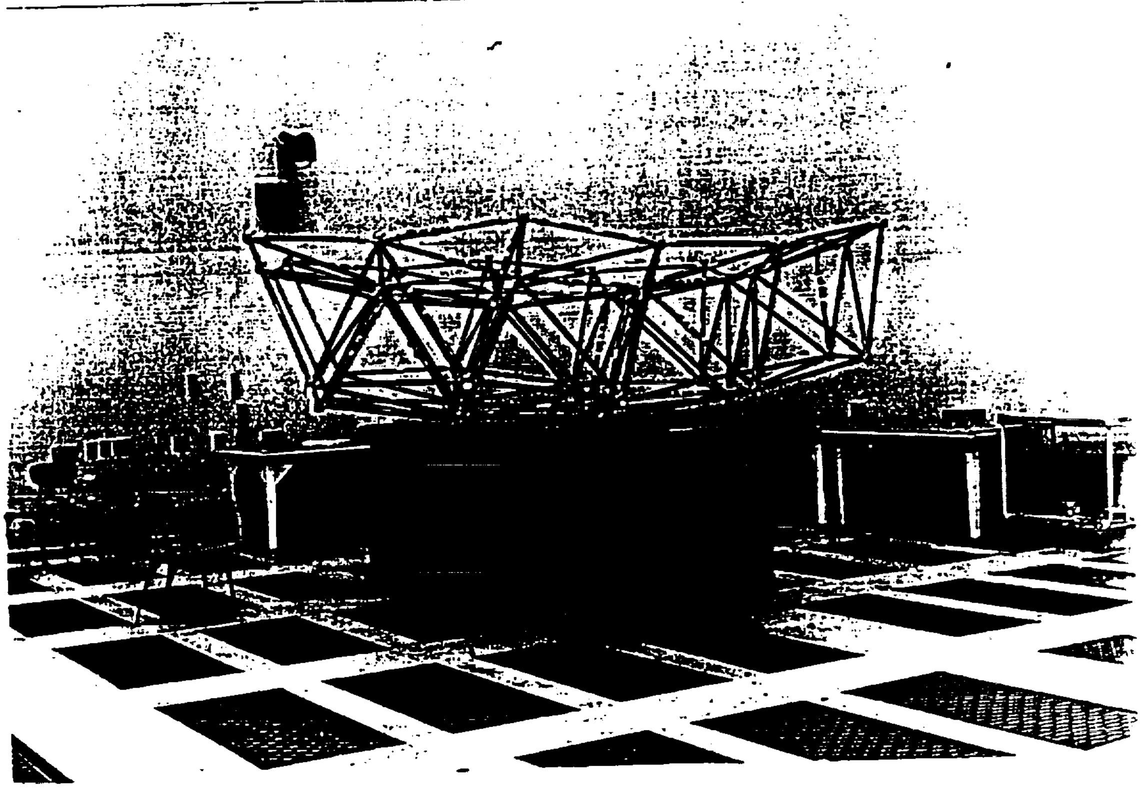
PANEL ATTACHMENT CONCEPT (ASTRO)



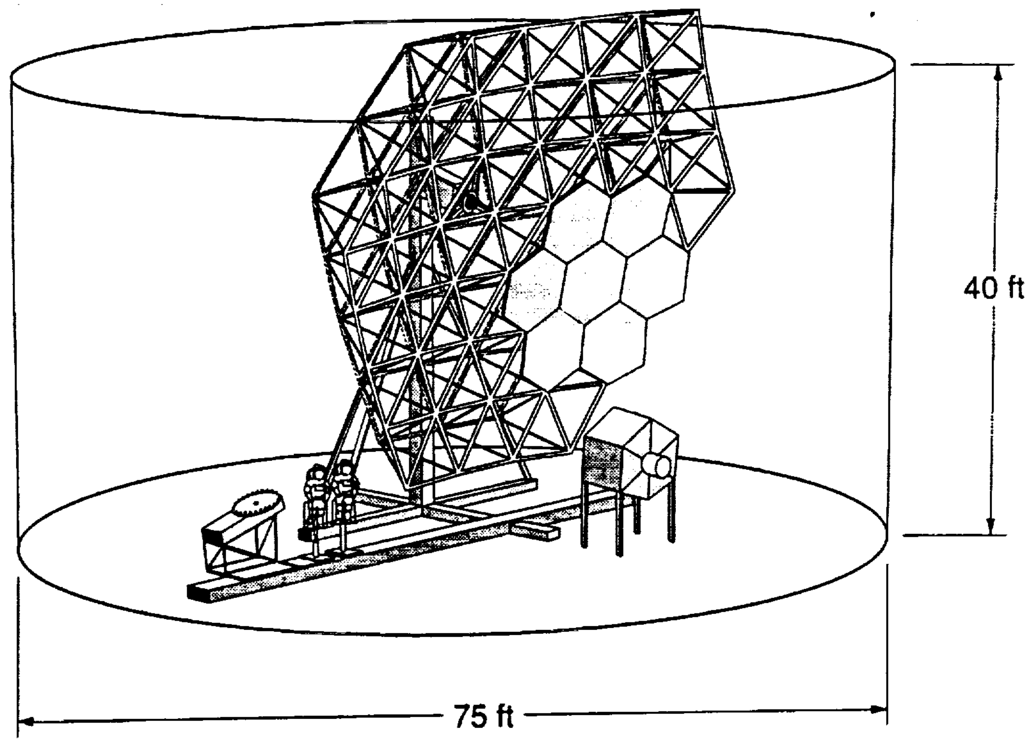
PANEL INSTALLATION SYSTEM HARDWARE FABRICATED FOR ROBOTIC TRUSS ASSEMBLY



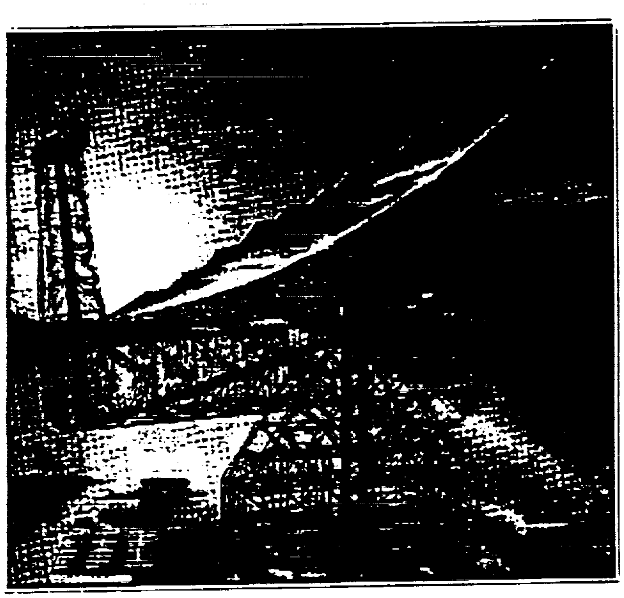
PRECISION SEGMENTED REFLECTOR TEST BED TRUSS DELIVERED TO JET PROPULSION LABORATORY



PRECISION STRUCTURE
NEUTRAL BUOYANCY CONSTRUCTION EXPERIMENT



NATIONAL RADIO ASTRONOMY OBSERVATORY GREEN BANK TELESCOPE DEVELOPMENT
Green Bank, West Virginia



FACT SHEET

- Offset fed parabola. reflector diameter: 100m
- Number of reflector facets (panels) 2,006
- Surface accuracy. 0.001inches
- Computer shape control (screw-type actuators)
- Laser ranging system for surface measurements
- 12 million pounds of steel
- Finite element modeling
- Completion date, September 1994
- Contractor, Radiation Systems. Inc.

STRUCTURES

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TECHNOLOGY CHALLENGES/APPROACH

CHALLENGES

- Lightweight erectable structures with complex geometries that can be quickly, and efficiently constructed on-orbit
- Deployable structures comparable in weight to erectable structures and which will reliably deploy in space
- Assuring precise initial on-orbit shape and long-term stability
- Integratlion of utilities (fluid and electrical lines)
- Lightweight debris/micrometeoroid protection integrated into large enclosures on LEO manned platforms
- Design methods for hybrid erectable/deployable concepts that significantly reduce weight, risk and cost
  - Example: Deployable parabolic antenna truss with a constructed solid surface
  - Example: Erectable frame with deployable walls for a large enclosure
- Assure on-orbit structural performance: static shape and dynamics
- Minimize packaging volume

STRUCTURES

OAET

TECHNOLOGY CHALLENGES/APPROACH

APPROACH

- Develop structural requirements based on a mission set that:
  - Covers the range of likely mission applications
  - Provides a set of complete, realistic structural performance requirements derived from realistic classes of mission performance requirements
  - Defines relationship between structural systems and other platform systems to assure compatibility

  Initial emphasis on science missions: Mission to Planet Earth

- Develop analysis and design methods in parallel with component and system level concepts
- Develop critical component level concepts in full-scale
- Validate system level concepts in sub-scale
  - Large enough to demonstrate full-scale performance and scaling
  - Small enough to be economical
- Incorporate CSI structural control and adaptive structures concepts and dynamics test methods
- Maintain close coordiantion with In-Space Assembly and Construction to assure constructibility and guide space construction activities

STRUCTURES

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AUGMENTED PROGRAM - WORK BREAKDOWN STRUCTURE

1.0 ANALYSIS & SIMULATION METHODS
2.0 ANTENNA AND RADIOMETER STRUCTURES *
  2.1 DOUBLY CURVED REFLECTOR SUPPORT TRUSS
  2.2 FEED SUPPORT STRUCTURE
  2.3 SURFACE PANELS (20-90 GHZ)
    2.3.1 PANEL SUPPORT-PASSIVE
    2.3.2 PANEL SUPPORT-FIGURE INITIALIZATION AND / OR MAINTENANCE
3.0 KEEL STRUCTURES *
  3.1 BEAM TRUSSES
  3.2 AREA TRUSSES
4.0 ENCLOSED STRUCTURES *
  4.1 UNPRESSURIZED (SHELTERS)
  4.2 PRESSURIZED (HABITATS)

* erectable & deployable structures considered in parallel

STRUCTURES

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SCHEDULE

KEY ACTIVITIES	1993	1994	1995	1996	1997	1998	1999
ANALYSIS & SIMULATION	radiometer dynamic simulation		radiometer thermal analysis				
PRECISION ANTENNAS AND RADIOMETERS	14 m erectable truss structural tests; panel fabrication method; assembly and / or deployment studies	14 m erectable radiometer reflector tests; passive panel supports	adjustable panel supports	14 m radiometer & feed structural tests	near-field scanning microwave radiometer test		EOS radiometer flight experiment
KEEL TRUSSES	erectable feed booms	deployable feed booms			adaptive platform-antenna mount		
ENCLOSURES							deployable enclosures

N93-71843

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IN-SPACE ASSEMBLY AND CONSTRUCTION TECHNOLOGY PROJECT SUMMARY

INFRASTRUCTURE OPERATIONS AREA OF THE OPERATIONS TECHNOLOGY PROGRAM

June 26, 1991

Office of Aeronautics, Exploration and Technology
National Aeronautics and Space Administration

Washington, D.C. 20546

OPERATIONS TECHNOLOGY

INFRASTRUCTURE OPERATIONS

In-Space Assmbly and Construction

OBJECTIVES

- Programmatic

Develop and Demonstrate an In-Space Assembly and Construction Capability for Large and/or Massive Spacecraft

SCHEDULE

- 1993 Automated panel installation on truss
  Complete welding vacuum facility
- 1994 Demonstrate precise 2-D crane positioning
- 1995 Demonstrate automated "orbital" welding
- 1997 Controlled slewing of 3-D space crane
- 1998 Precise positioning of large component
- 1999 Automated construction of curved antenna

RESOURCES

- 1991 $ 0.3M
- 1992 $ 0.0M
- 1993 $ 2.0M
- 1994 $ 4.0M
- 1995 $ 7.0M
- 1996 $ 8.0M

PARTICIPANTS

Langley Research Center

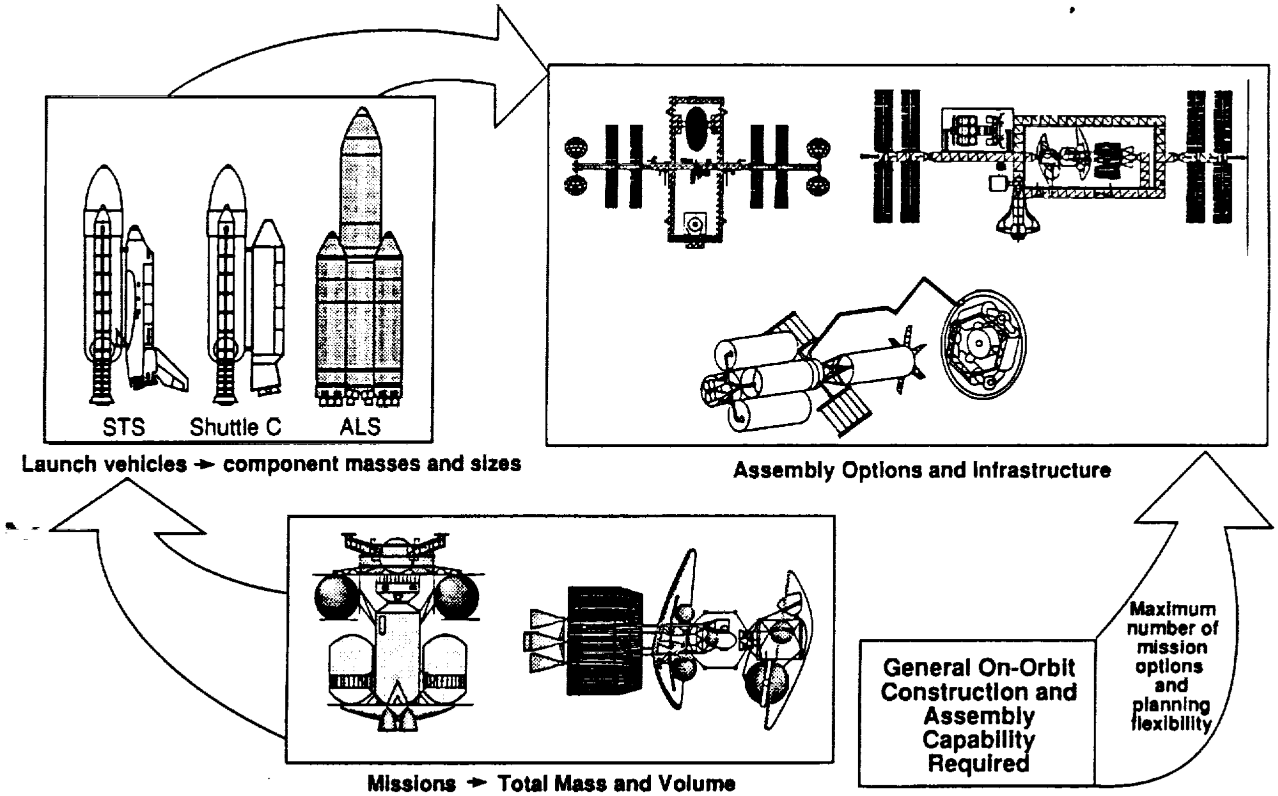
Space crane
- Positioning control
- Passive damping
- Active damping
- Suspension systems

Automated construction

Marshall Spaceflight Center

Automated welding

IN-SPACE ASSEMBLY AND CONSTRUCTION ENHANCES FUTURE MISSIONS PLANNING FLEXIBILITY



OPERATIONS TECHNOLOGY: INFRASTRUCTURE OPERATIONS

IN-SPACE ASSEMBLY AND CONSTRUCTION

TECHNOLOGY NEEDS

THE IN-SPACE ASSEMBLY AND CONSTRUCTION TECHNOLOGY PROGRAM WILL SUPPORT THE NEED TO BUILD, ON ORBIT, THE FULL RANGE OF SPACECRAFT REQUIRED FOR THE MISSIONS TO AND FROM PLANET EARTH, INCLUDING:

EARTH-ORBITING PLATFORMS

- EARTH OBSERVATION SYSTEM (PLATFORMS
- PRECISION RADIOMETER & ANTENNAE
- EVOLUTIONARY SPACE STATION

LUNAR TRANSFER VEHICLES

- AEROBRAKE CONSTRUCTION
- SPACECRAFT COMPONENT ASSEMBLY

MARS TRANSFER VEHICLES

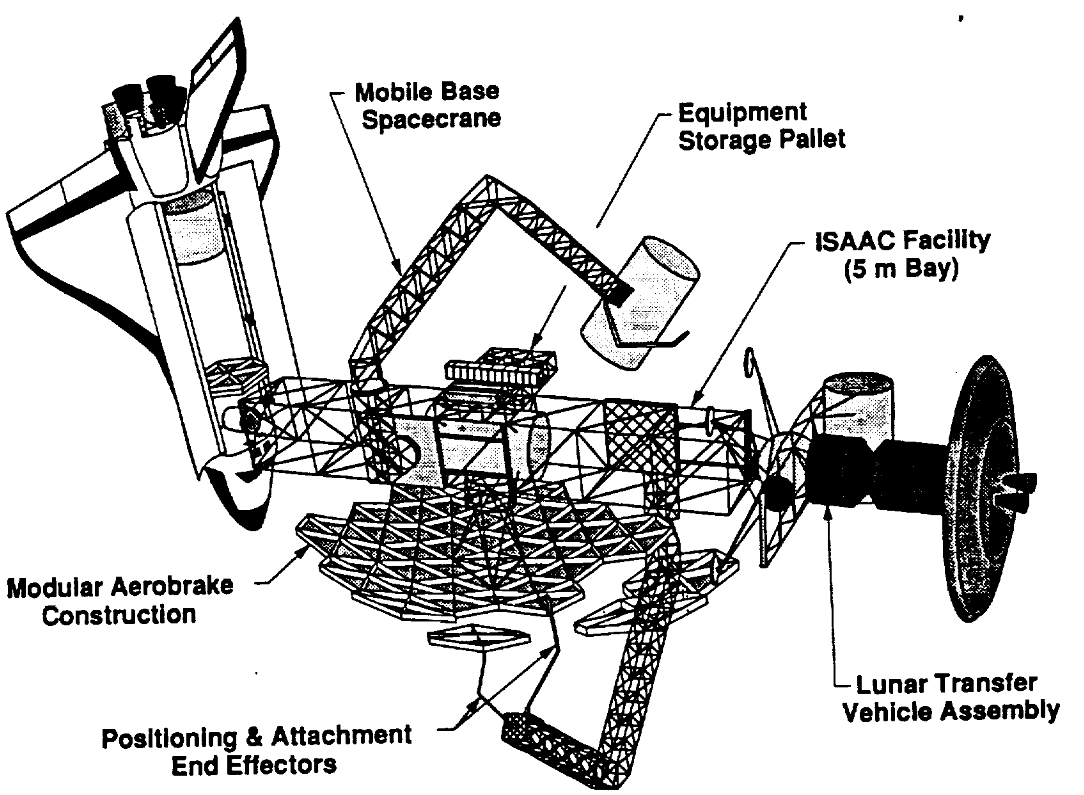
- SPACECRAFT COMPONENT ASSEMBLY
- NTR: BACKBONE TRUSS & RADIATOR CONSTRUCTION, UTILITIES WELDING
- SEP: SOLAR ARRAY CONSTRUCTION

IN-SPACE ASSEMBLY AND CONSTRUCTION

TECHNOLOGY CHALLENGES/APPROACH

- TECHNOLOGY DEVELOPMENT CHALLENGES:
  - REDUCE LIMITATIONS ON SPACE VEHICLE SIZES AND CONFIGURATIONS IMPOSED BY LIMITED ETO LAUNCH CAPABILITY AND/OR ON-ORBIT OPERATIONS REQUIREMENTS
  - SPECIFIC CHALLENGES INCLUDE:
    - ACCURATELY POSITION LARGE SPACECRAFT COMPONENTS
    - ASSEMBLY TWO OR MORE LARGE COMPONENTS TO FORM SPACECRAFT
    - CONSTRUCT DISCRETE SINGLE-POINT JOINTS
    - CONSTRUCT DISCRETE MULTI-POINT JOINTS
    - CONSTRUCT CONTINUOUS "LINE" JOINTS
    - AUTOMATE ASSEMBLY AND CONSTRUCTION OPERATIONS
    - ANALYZE AND SIMULATE ALL ASSEMBLY AND CONSTRUCTION OPERATIONS
- TECHNOLOGY DEVELOPMENT APPROACH
  - SURVEY MISSIONS FOR ISAAC NEEDS AND REQUIREMENTS
  - DEFINE FUNDAMENTAL GENERIC CAPABILITIES NEEDED
  - DEFINE FOCUS PROBLEMS AND ASSOCIATED EXPERIMENTS
  - DEVELOPE METHODS AND HARDWARE FOR ACCOMPLISHING ISAAC PROCESSES
  - PERFORM EXPERIMENTS WHICH VALIDATE ISAAC METHODS

IN-SPACE ASSEMBLY AND CONSTRUCTION FACILITY CONCEPT



OPERATIONS TECHNOLOGY: INFRASTRUCTURE OPERATIONS

IN-SPACE ASSEMBLY AND CONSTRUCTION

STATE-OF-THE-ART ASSESSMENT

- GENERAL ASSESSMENT: EXTENSIVE NEUTRAL BUOYANCY EXPERIENCE IN SIMULATED ZERO-G CONSTRUCTION OF LARGE SPACE TRUSSES. VERY GOOD CORRELATION WITH FLIGHT DATA (ACCESS). NO EXPERIENCE IN THE AREAS OF ON-ORBIT ASSEMBLY (AUTOMATED) OR AUTOMATED (TELEROBOTIC) CONSTRUCTION
- DETAILED ASSESSMENT:
  - NO VALIDATED DESIGN-FOR-CONSTRUCTION METHODS
  - NO SYSTEM EXISTS FOR RAPIDLY & PRECISELY POSITIONING LARGE/MASSIVE SPACECRAFT COMPONENTS (FOR ASSEMBLY)
  - CONCEPTS EXIST FOR LIGHTLY MECHANICAL LOADED JOINTS (ACCESS, SSF), HOWEVER, NO CONCEPTS EXIST FOR HEAVILY LOADED JOINTS
  - LIMITED EXPERIENCE WITH ZERO-G WELDING (SKYLAB, SOVIET UNION), HOWEVER, NO EXPERIENCE WITH AUTOMATED ZERO-G VACUUM WELDING FOR CONSTRUCTION OR ASSEMBLY APPLICATIONS ON ORBIT

OPERATIONS TECHNOLOGY: INFRASTRUCTURE OPERATIONS

IN-SPACE ASSEMBLY AND CONSTRUCTION

STATE-OF-THE-ART ASSESSMENT

DETAILED ASSESSMENT (CONCLUDED):

- AUTOMATED CONSTRUCTION OF A LIGHTLY LOADED TRUSS IN A HIGHLY STRUCTURED ENVIRONMENT WITH NO ON-ORBIT EFFECTS INCLUDED (ASAL). NO EXPERIENCE WITH AUTOMATED ASSEMBLY OR CONSTRUCTION IN AN UNSTRUCTURED ENVIRONMENT INCLUDING PATH PLANNING, COLLISION AVOIDANCE, AND FACILITY INFRASTRUCURE FLEXIBILITY.

IN-SPACE ASSEMBLY AND CONSTRUCTION

POSITIONING AND CONSTRUCTION DEVICES PERFORMANCE OBJECTIVES

PERFORMANCE REQUIREMENT	CURRENT S.O.A. (RMS)	LUNAR	MARS
Manipulator Reach	15 m	30 m	100 m
Component Mass	14,500 kg (ret.) 30,000 kg (dep.)	75, 000 kg	150,000 kg
Placement Accuracy	± 2 inches	± 1 inch	± 1 inch
Tip Force	15 lbf	50 lbf	150 lbf
Damping	< .5%	> 5.0% (5 modes)	> 5.0% (5 modes)
Max. tip velocity (14,500 kg, 2 ft. stop)	0.2 ft/sec	0.4 ft/sec	0.6 ft/sec
Maintenance Interval	After each flight	> 1year	> 1 year
Required environment	Highly structured taught points	Unstructured path planning	Unstructured path planning
Operation	Teleoperated	Telerobotic	Telerobotic

SPACE CRANE

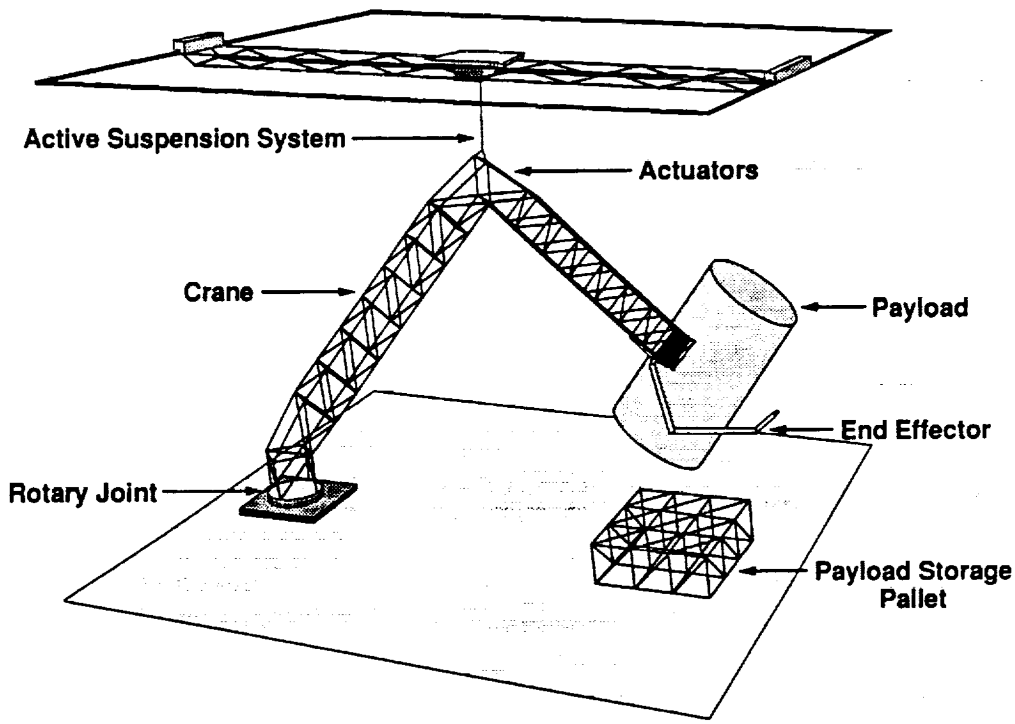
The Capability to Position and Control Spacecraft Components.Precisely and Safely During Assembly Will be Achieved by Developing a Structural Space Crane Type Arm, Having Multiple Articulating Joints for Dexterity, and that can Ultimately be Operated in an Automated Mode

FEATURES

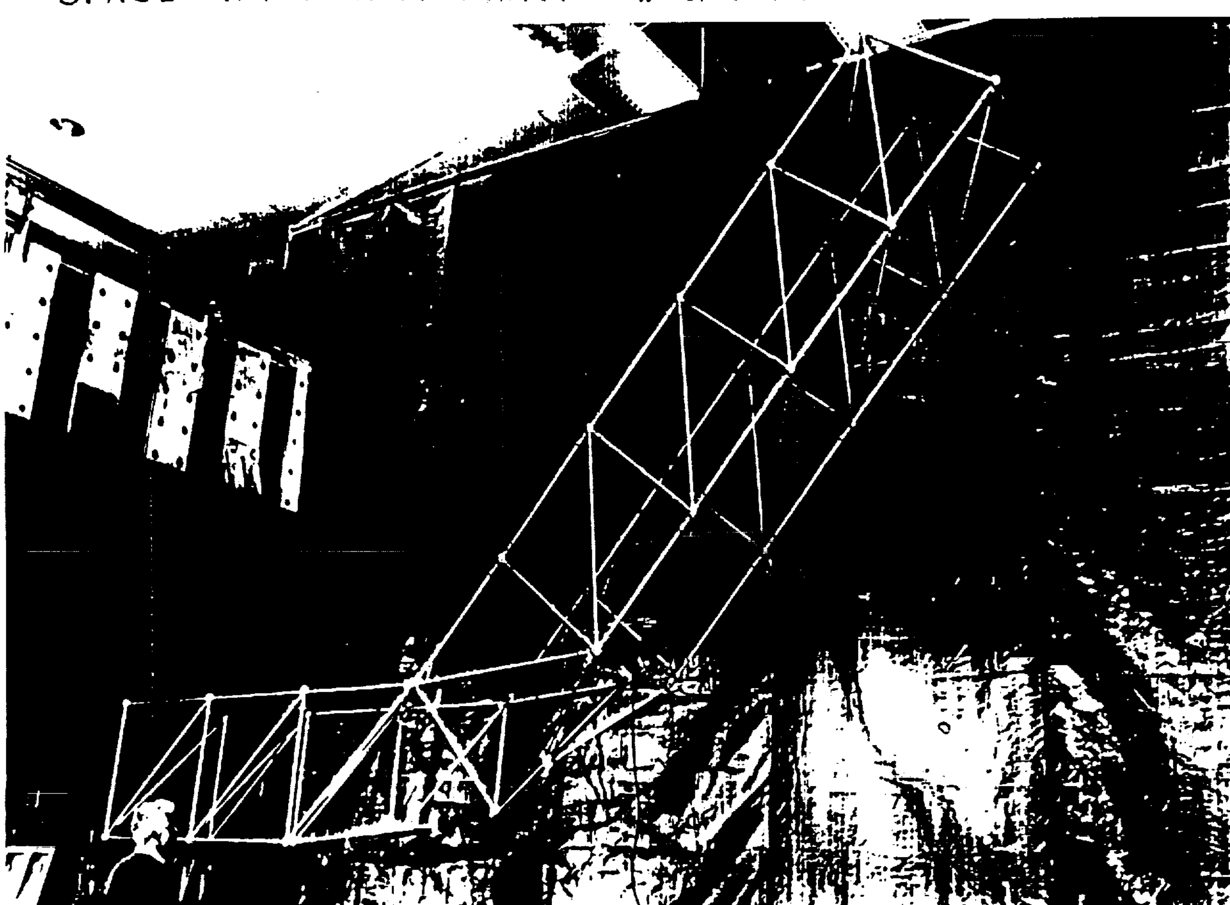
- Strength to Move and Control Large Spacecraft Components Safely
- Passive and Active "Stiffness" to Maintain a Stable and Secure Position
- Highly Controllable Large Angle Motion with Dynamic Control for Stable Trajectories
- Passive and Active Vibration Damping to Achieve Required Precision
- Reconfigurable/Adaptable Geometry to Reduce the Amount of Required On-Orbit Infrastructure
- Scaleability (Larger or Smaller Sizes) for a Variety of Applications
- Robustness and Reuseability for Long Life

NASA

SPACECRAFT COMPONENT POSITIONING AND ASSEMBLY TEST-BED

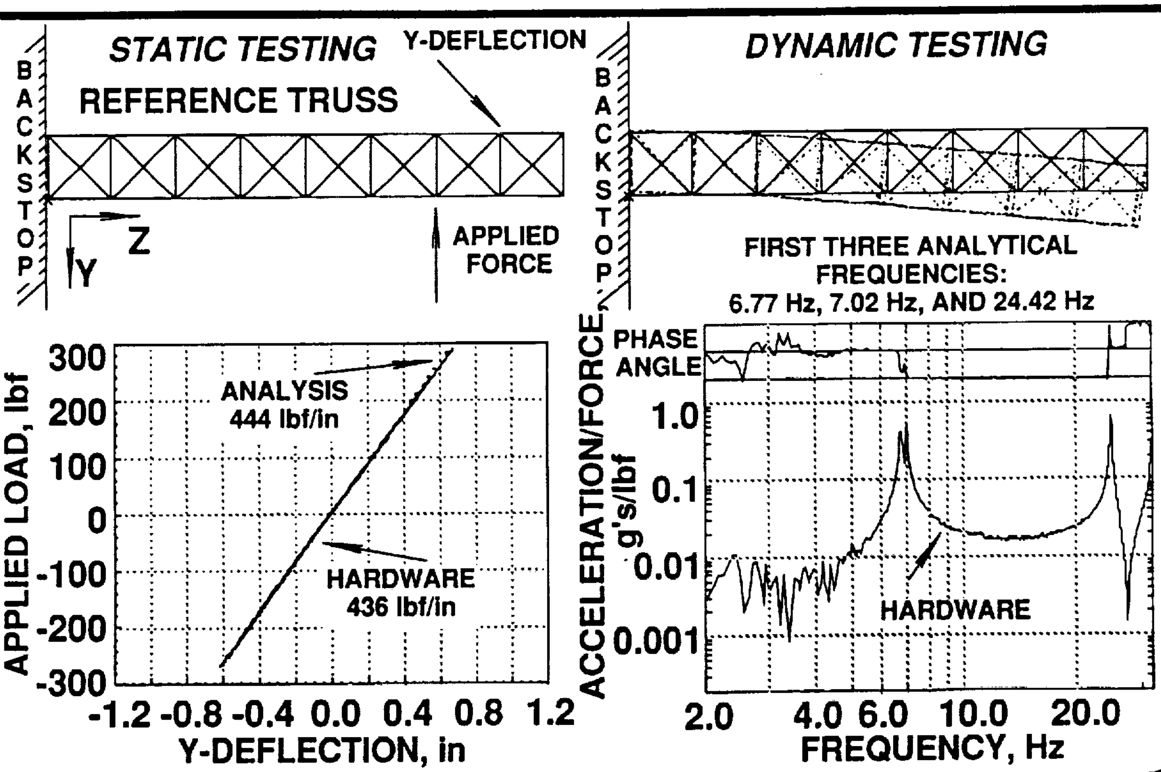


SPACE CRANE ARTICULATING JOINT TEST BED FABRICATED



ERECTABLE TRUSS HARDWARE PREDICTABILITY IS EXCELLENT

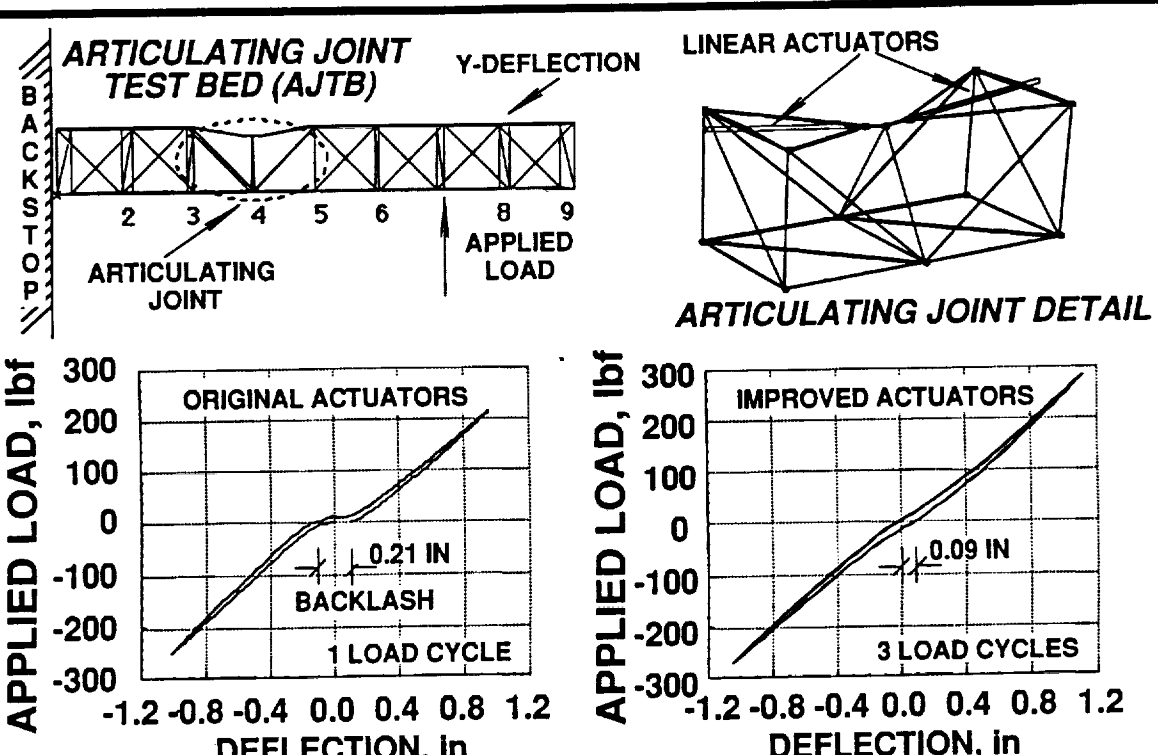
EXPLORATION TECHNOLOGY



NASA Langley Research Center

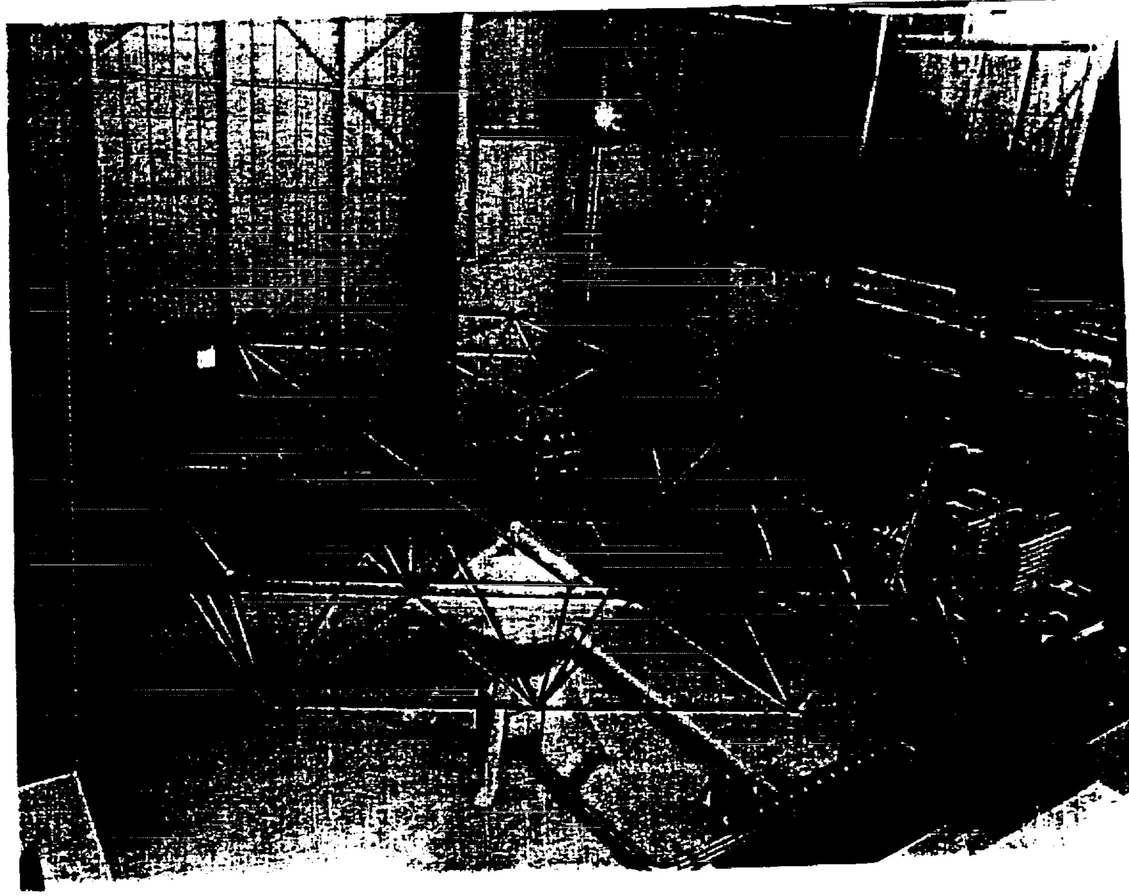
IMPROVED LINEAR ACTUATORS REDUCE TEST BED BACKLASH BY 57 PERCENT

EXPLORATION TECHNOLOGY

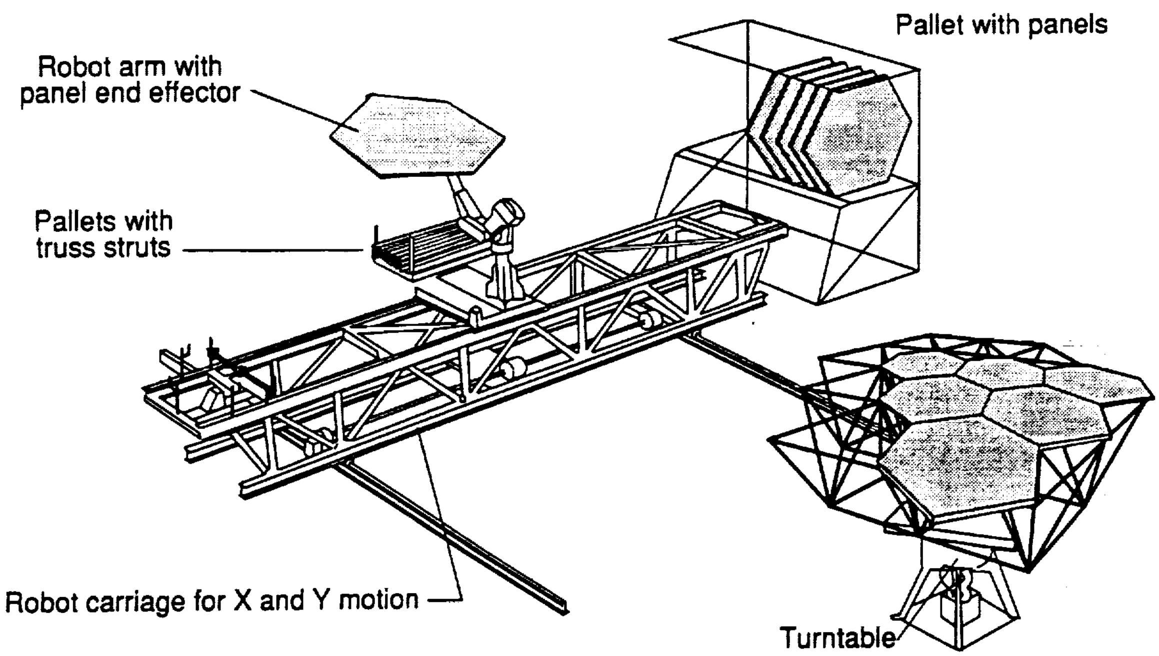


NASA Langley Research Center

AUTOMATED STRUCTURES ASSEMBLY LABORATORY



AUTOMATED CONSTRUCTION TECHNOLOGY DEVELOPMENT & DEMONSTRATION TEST-BED

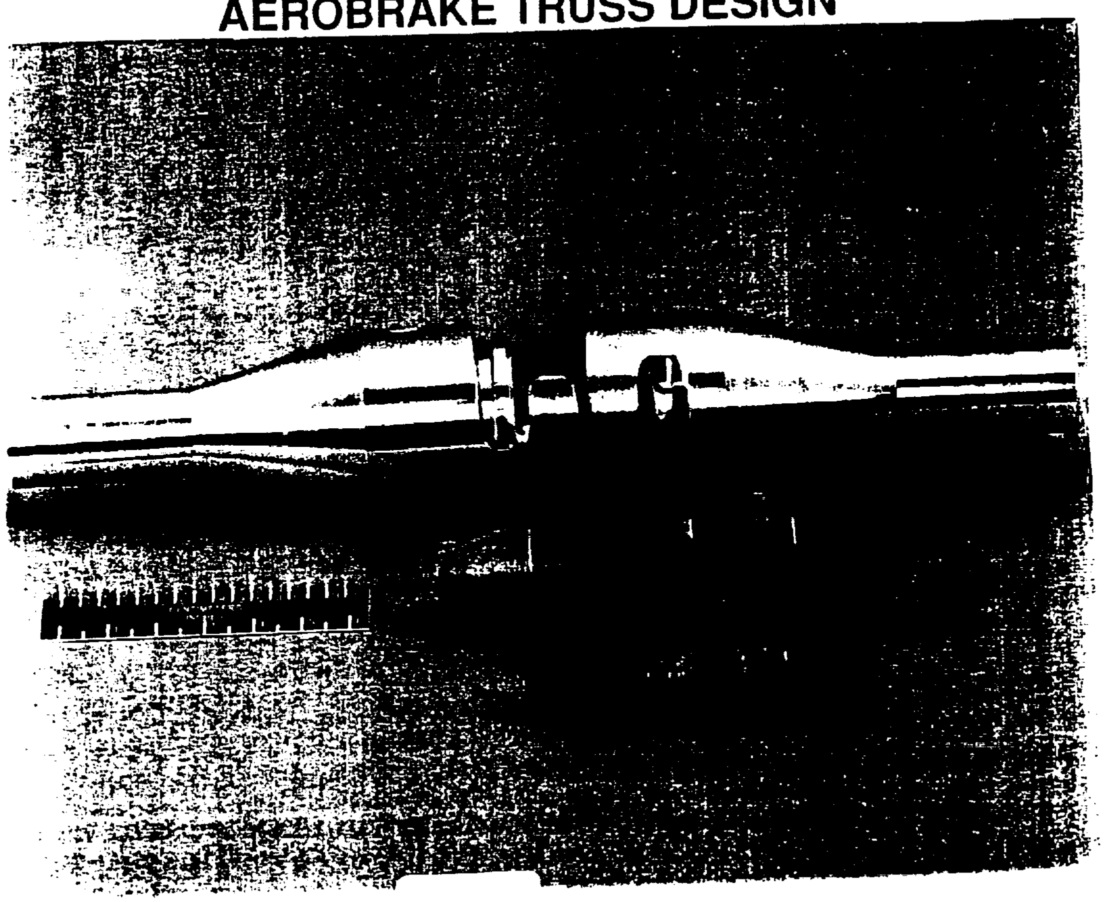


IN-SPACE ASSEMBLY AND CONSTRUCTION

JOINING METHODS PERFORMANCE OBJECTIVES

PERFORMANCE REQUIREMENT	CURRENT S.O.A.	LUNAR	MARS
Strength	2000 lbf (SSF)	Up to 50,000 lbf	Up to 150,000 lbf
Connection time	0.3 min/strut (ACCESS)	0.3 - 5.0 min/strut (mechanical) Welding: TBD	0.3 - 5.0 min/strut (mechanical) Welding: TBD
Durability	> 5years (SSF)	> 5 years	> 10 years
Connection method	Manned EVA (ACCESS, SSF)	Automated/EVA (mix)	Automated/EVA (mix)

ERECTABLE JOINT FAMILY AVAILABLE FOR EFFICIENT AEROBRAKE TRUSS DESIGN



WELDED JOINTS - CLASSIFICATION (Basic Advantages)

- TUBULAR STRUT
  - High Strength, Low Mass
  - Low Dimensional Accuracy Requirements
  - Simple Welding Mechanism

- PIPES/DUCTS
  - Hermetic Seal
  - Simple Welding Mechanism

- SKIN/TANK
  - Hermetic Seal

- SEMI-MONOCOQUE STRUCTURES
  - High Strength, Low Mass
  - Low Dimensional Accuracy Requirements

- REPAIR/CONTINGENCY (Manual)
  - Flexibility

OPERATIONS TECHNOLOGY: INFRASTRUCTURE OPERATIONS

IN-SPACE ASSEMBLY AND CONSTRUCTION

CURRENT PROGRAM: ACCOMPLISHMENTS

ACCOMPLISHMENTS

- Load/displacement testing of 1st and 2nd generation space crane linear actuators completed
- Space crane maximum allowable tip velocity established using strut buckling loads
- 1st. generation heavily loaded 4-inch diameter erectable aerobrake joint developed
- Automated construction of the complete 102-member flat tetrahedral truss structure successfully completed
- Vacuum plasma welding experiments conducted
- Aerobrake hexagonal heatshield panel construction tests completed

OPERATIONS TECHNOLOGY: INFRASTRUCTURE OPERATIONS

IN-SPACE ASSEMBLY AND CONSTRUCTION

CURRENT PROGRAM: FY 91/92 PLANS

FY 91/92 PLANS (FUNDING FOR FY 92 = $0)

- Perform space crane kinematic and dynamic simulations
- Upgrade space crane articulating joint test hardware and perform dynamic tests
- Redesign heavily-loaded erectable joints and perform static tension failure tests
- Demonstrate automated installation of flat antenna panels onto flat truss
- Complete welding vacuum manipulation facility

OPERATIONS TECHNOLOGY: INFRASTRUCTURE OPERATIONS

IN-SPACE ASSEMBLY AND CONSTRUCTION

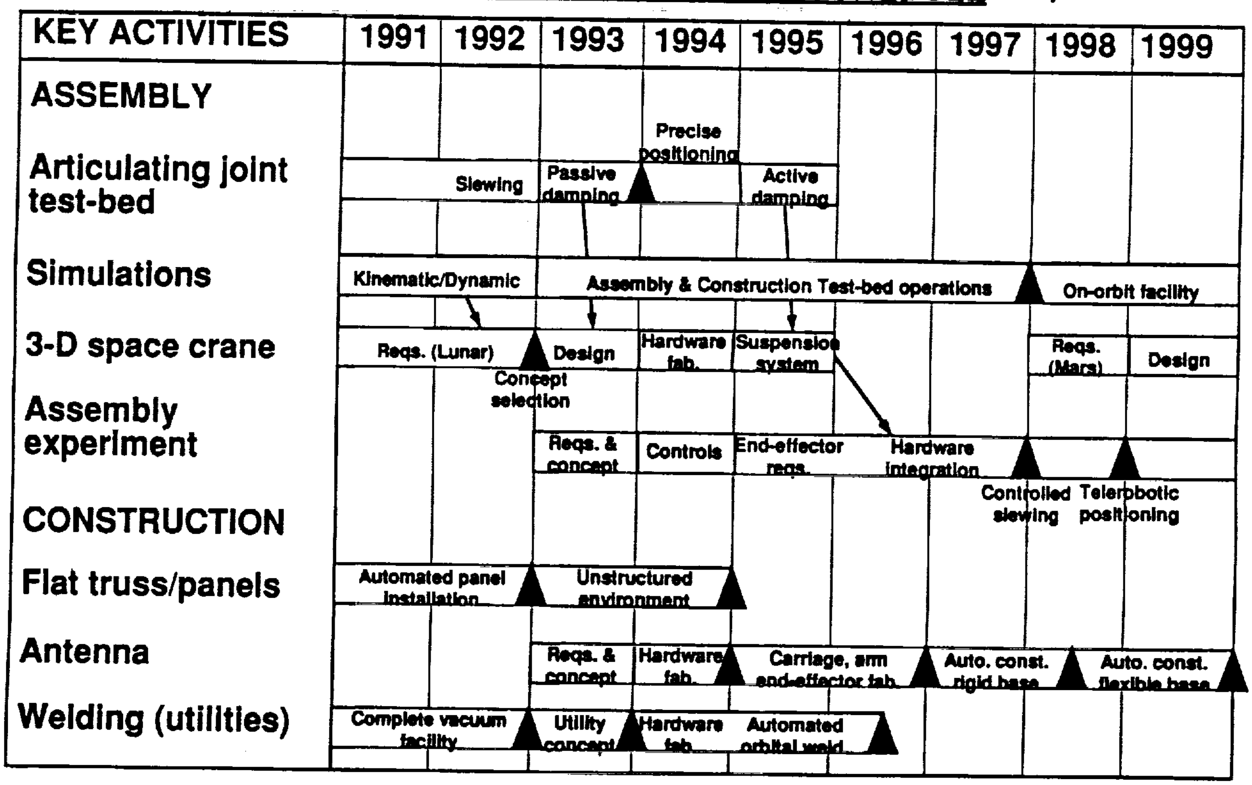
OTHER DEVELOPMENT EFFORTS

- LaRC BASE R&T
  - EVA construction of precision curved truss with panels
  - Automated Structures Assembly Laboratory (ASAL)

- NO OTHERS

IN-SPACE ASSEMBLY AND CONSTRUCTION

ISAAC TECHNOLOGY ROADMAP/SCHEDULE



CONCLUDING REMARKS

- Design-for-Construction/Assembly Must be Emphasized From the Very Beginning of the Spacecraft Design Process

- Having a Basic Generic Set of In-Space Assembly and Construction Capabilities Available Will
  - Give Mission Planners and Spacecraft Designers a Great Deal of Flexibility
  - Minimize the Amount of In-Space Infrastructure and Resources Required to Build Spacecraft on Orbit

- Spacecraft Design Costs can be Reduced by Using Available and Developed ISAAC Capabilities, Methods, and Hardware

MATERIALS AND STRUCTURES DIVISION

OAET

INTEGRATED TECHNOLOGY PLAN
FOR THE CIVIL SPACE PROGRAM

N93-71844

SPACE TRANSPORTATION PRESENTATION TO SSTAC/ARTS REVIEW COMMITTEE

510-81
157520
P- 24

Samuel L. Venneri
Director
Materials and Structures Division

JUNE 27, 1991

OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON, DC 20546

ADVANCED LAUNCH DEVELOPMENT PROGRAM

NATIONAL SPACE COUNCIL DIRECTION

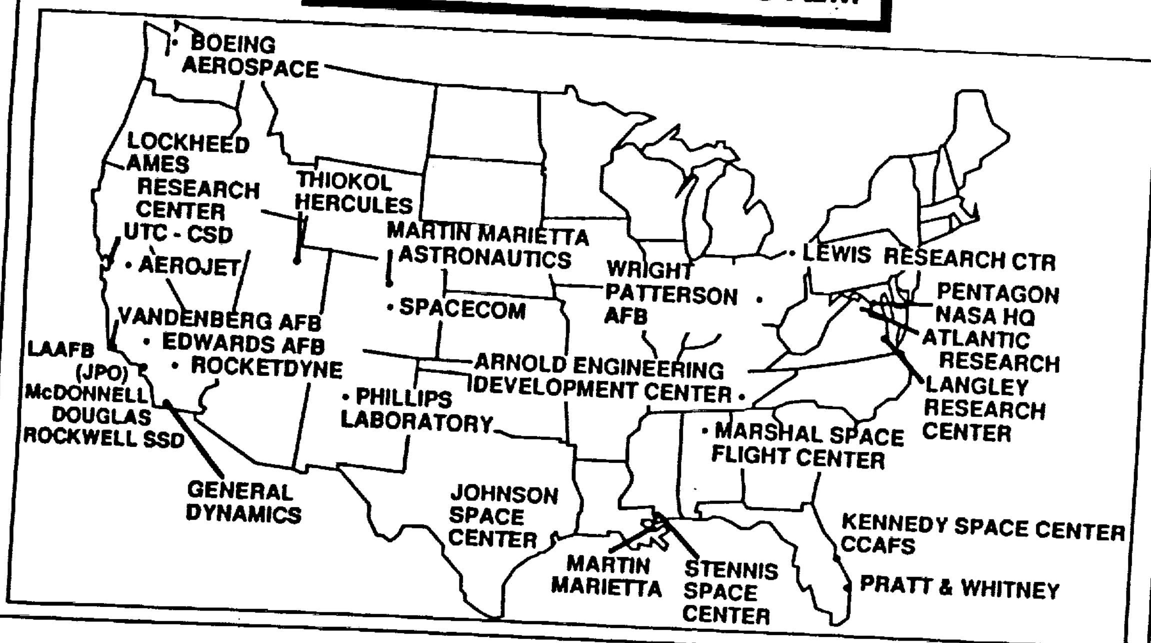
APRIL 16, 1991

Department of Defense and NASA will jointly develop and jointly fund development of a new space launch system to meet civil and national space needs; will actively consider commercial space needs.

- GOALS:
  - GREATLY IMPROVE NATIONAL LAUNCH CAPABILITY
  - REDUCE OPERATING COSTS
  - IMPROVE RELIABILITY, RESPONSIVENESS AND MISSION PERFORMANCE
- DIRECTION:
  - SUPPORT A RANGE OF MEDIUM TO HEAVY-LIFT PERFORMANCE REQUIREMENTS
  - FACILITATE EVOLUTIONARY CHANGE AS REQUIREMENTS EVOLVE
  - MAY TAKE ADVANTAGE OF EXISTING COMPONENTS TO EXPEDITE INITIAL CAPABILITY AND REDUCE DEVELOPMENT COSTS
  - INITIALLY UNMANNED, BUT DESIGNED TO BE MAN-RATABLE
- DEVELOPMENT GOAL - FIRST FLIGHT IN 1999
  - MAINTAIN FLEXIBILITY FOR SEVERAL SCHEDULE OPTIONS
  - IDENTIFY KEY INTERMEDIATE MILESTONES
  - FINAL DECISION WILL BE MADE DURING 1993

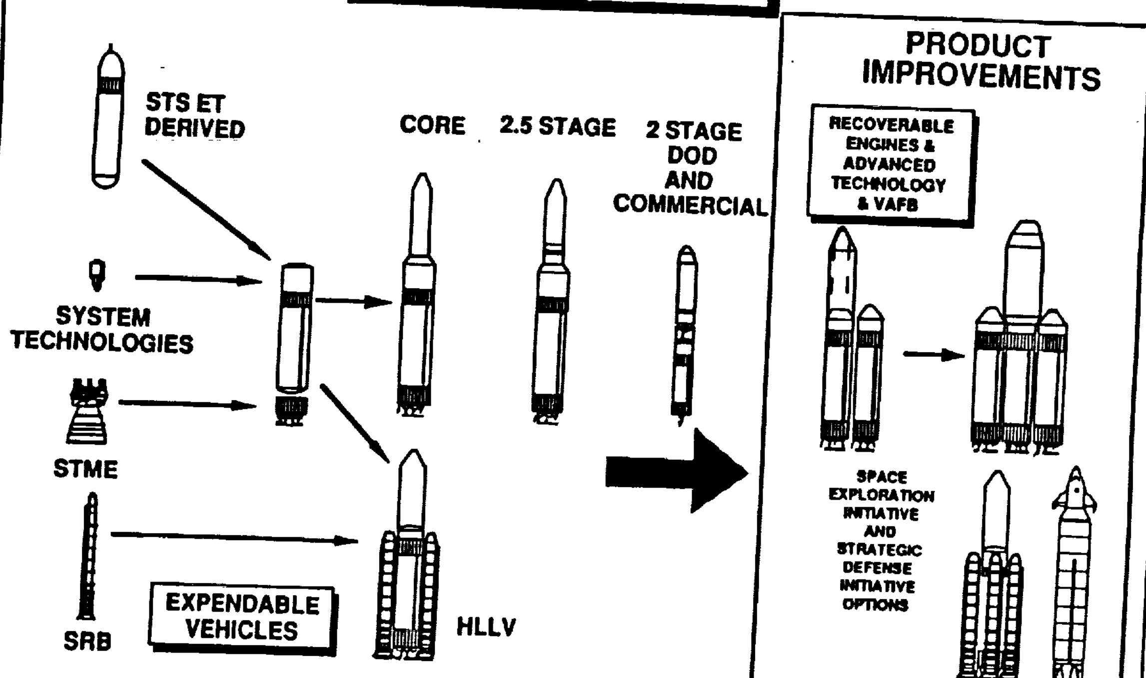
ADVANCED LAUNCH DEVELOPMENT PROGRAM

NATIONWIDE PARTICIPATION IN NATIONAL LAUNCH SYSTEM



ADVANCED LAUNCH DEVELOPMENT PROGRAM

VEHICLE EVOLUTION



ADVANCED DEVELOPMENT PROGRAM KEY TECHNOLOGIES

COMPONENT AND MANUFACTURING DEVELOPMENT FOR STME
ADVANCED AVIONICS (MULTIPATH AND FAULT TOLERANT)
ELECTROMECHANICAL ACTUATORS
LASER INITIATED PYROTECHNICS
INTEGRATED GROUND AND FLIGHT INFORMATION SYSTEMS
ADVANCED SIMPLIFIED STRUCTURES & MANUFACTURING PROCESSES
RECOVERY AND REFURBISHMENT

ADVANCED LAUNCH DEVELOPMENT PROGRAM

ADP OBJECTIVES BY AREA (CON'T)

STRUCTURES

- QUALIFY ALUMINUM LITHIUM ALLOY STRUCTURE WITH LOW-COST FABRICATION, AUTOMATED ASSEMBLY, AND STATISTICAL PROCESS CONTROLS

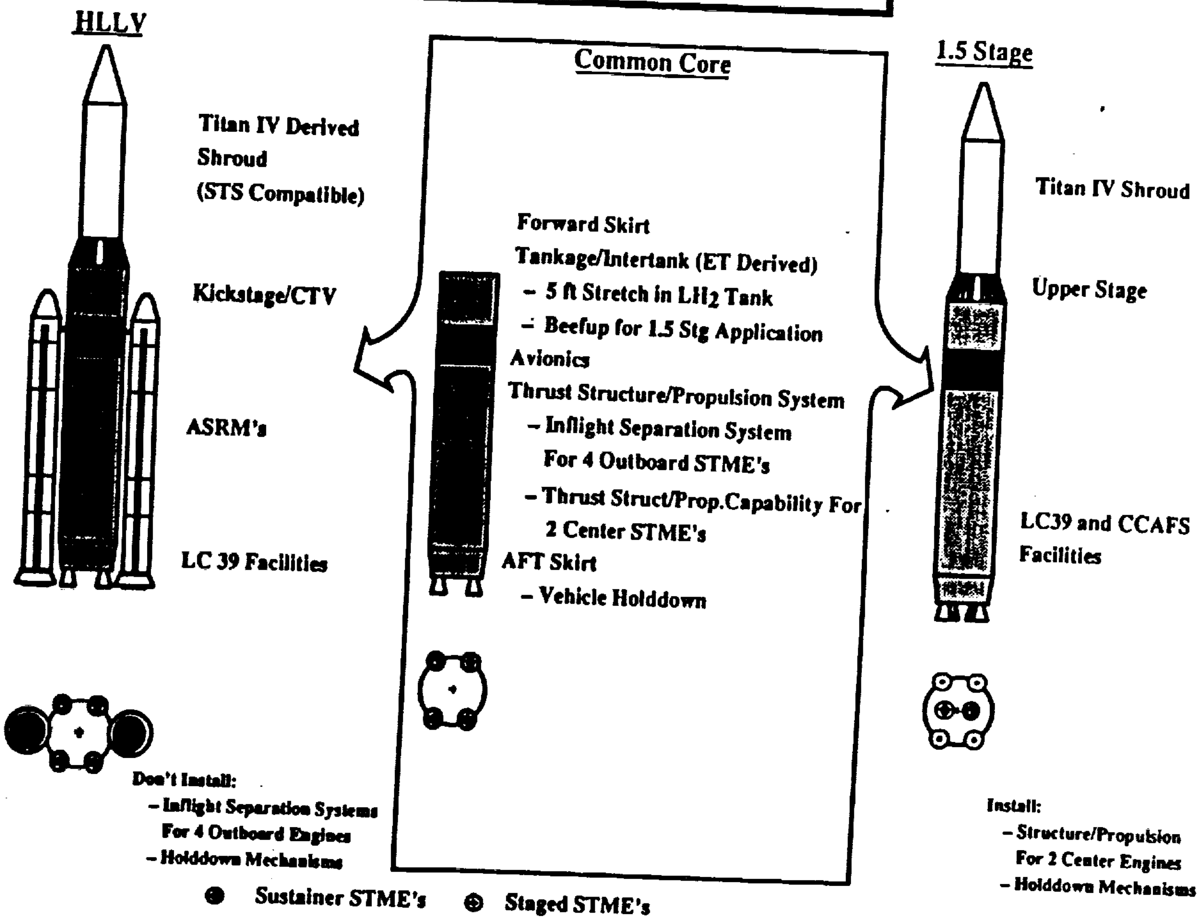
AEROTHERMODYNAMICS

- DEMONSTRATE ENGINES (AND AVIONICS) RECOVERY / REFURBISHMENT / MAINTENANCE

OPERATIONS

- STREAMLINE MANUFACTURING AND LAUNCH INFORMATION PROCESSING (PAPERLESS MANAGEMENT)
- REDUCE MANPOWER REQUIRED FOR LAUNCH CONTROL THROUGH AUTOMATION AND ARTIFICIAL INTELLIGENCE APPLICATIONS
- REDUCE TIME ON-PAD THROUGH EFFICIENT SUBSYSTEMS EG LASER INITIATED PYROTECHNICS AND REMOTE CABLE IDENTIFICATION

National Launch Vehicles



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STRUCTURAL MASS FRACTIONS OF CURRENT AEROSPACE SYSTEMS

AIRCRAFT (EMPTY)	
FIGHTER	50%
TRANSPORT	60%
ELV	10%-15% (6% when dynamics are well known)
STS	
ORBITER	25%-30%
ET	5%
SRB	APPROX. 10%
SPACECRAFT	25%
GALILEO	(27.5%)
VOYAGER	(23.5%)
VIKING	(24.2%)
ORBITING TELESCOPES	30%-50% (EST. INCLUDING OPTICS)
SSF HAB. MODULE	APPROX. 50%

GENERAL BENEFITS OVER CURRENT TECHNOLOGY

CURRENT BASELINE:

MATERIAL	ALUMINUM (TEMPERATURE BELOW 350 F) TITANIUM (TEMPERATURE UP TO 1000 F)	
CONSTRUCTION	MULTI-PART BUILD EXTENSIVE MACHINING (UP TO 80%WASTE)	
WEIGHT REDUCTION		
	TODAY	+5-7 YEARS
HEAVILY LOADED:	15%-20%	40%
LIGHTLY LOADED:	30%-40%	50%
COST SAVING	NONE	20%-30%

SPECIFIC WEIGHT & COST SAVING ESTIMATES	(LB)	% OF CURRENT WEIGHT (COST)
EXTERNAL TANK		
DIRECT SUBSTITUTION OF Al-Li	2150	3.3
REDESIGN FOR Al-Li	7300	11.2
EXPENDIBLE FUEL TANKS		
ADVANCED MATERIALS & STRUCTURES	20% - 65 %	(20% - 85%)

GENERAL BENEFITS OVER CURRENT TECHNOLOGY

MATERIAL SYSTEMS

Direct replacement by advanced materials can save approximately 15% in heavily loaded structures, 30% in lightly loaded structures

LIGHT METALS (Al-Li, Intermetallics)

ADVANCED PROCESSES

SPDF/DB

Complex loaded structures (vs AL):
25% lighter due to as much as 60% fewer parts

Rerference application: Aluminum cryotqnks
Current material waste up to 80%
SPDF/DB essentially no waste

LID (THIN GAGE HONEYCOMB STRUCTURE)

Ti-Al Honeycomb - .05 lb/sq. ft.

GENERAL BENEFITS OVER CUTRRENT TECHNOLOGY

METAL MATRIX COMPOSITES

Thin gage 10 mills has been fababricated.
Twice the stiffness and 50% stronger than Al

ADVANCED PROCESSES
SPDF/DB
CVD
PM (HIP, ETC)

Fiber costs

Silicon carbide	
CVD	\$500-\$700/lb
Whisker & oxide	\$200/lb
Graphite	\$40-\$100/IB
Particulates	\$2-\$4/lb

Key applications

Beams and struts

GENERAL BENEFITS OVER CUTRRENT TECHNOLOGY

POLYMER MATRIX COMPOSITES

Fabrication costs currently still about 25% higher than Al for comparable structures. Costs can be reduced to below Al.

KEY APPICATIONS
Shells and beams
Stiffened plates
Stiffened plates
Complex shapes

Filament winding
Extrusion methods
Stiffened plates
Automatic lay-up

GENERAL BENEFITS OVER CUTRRENT TECHNOLOGY

STRUCTURAL CONCEPTS

Advanced construction methods are up an order of magnitude lighter than simple, current "low cost" fabrication methods

Projections are that advanced methods can be made 20%-30% lower in cost due to improved manufacturing operations (30% cost; 25% part count reduction)

GEODESIC CONSTRUCTION

30% higher buckling load than ordinary blade stiffened shell

HONEYCOMB

Al structure .07-.10 lb/sq. ft. structure can carry compressive loads up to 2000 lb/in. (2,000,000 lb load for a 30 ft. dia structure)

PMC honeycomb loaded shell structure cost can be reduced by half through adv. fab. methods

INTEGRAL CRYO-STRUCTURE

10% - 30%?? % lighter than separate tanks and structure for reusable tanks

Key applications

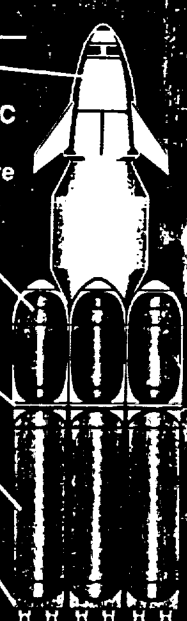
Long-duration space flight

Protection during asmospheric entry

VEHICLE STRUCTURES AND CRYOTANKS FOR EARTH TO ORBIT TRANSPORTATION

Materials

- PLS
  - Advanced C-C & TPS
  - Al-Li structure
- LOX tank
  - Al-Li
- Intertank
  - Gr/E
- LH_2 tank
  - Al-Li
- Aft skirt
  - Al-Li



Structures

- PLS
  - Improved design codes & aerothermal analysis
- Cryotanks
  - Design of net section and built-up Al-Li components
- Intertank
  - Design of Gr/E structure
  - Structural analysis of Al-Li, Gr/E interface

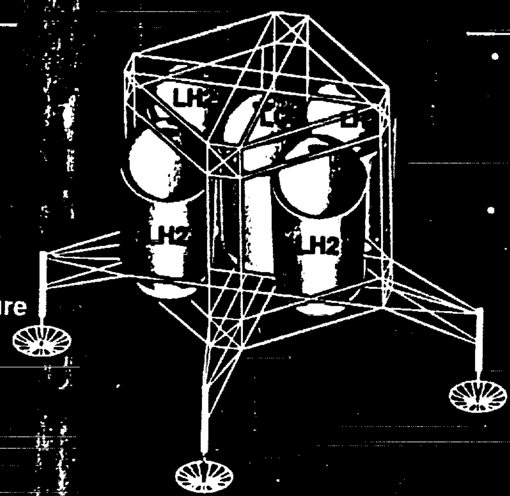
Benefits

- Advanced materials: 20-30% weight savings
  Improved durability & lighter weight TPS
  Increased payload capability
  Lower systems cost ($/lb to orbit)
- Low cost processing: 30% cost saving
  Reduced manufacturing time
- Advanced structural design & aerothermal analysis: Improved structural efficiency - lower weight
  Increased reliability

MATERIALS AND STRUCTURES TECHNOLOGY FOR SPACE TRANSFER VEHICLES

Cryotank

- Materials
  - Al-Li
  - SiCp/Al MMC
  - Ti
  - RMC
- Low cost fabrication
  - Spun formed domes
  - SPF, Built-up structure
  - Filament wound RMC tanks
  - Explosively formed components



Core primary structure

- Materials
  - Al-Li
  - B/Al MMC
  - Gr/E
- NDE/durable materials
  - Real time radiography
  - Advanced ultrasonics
  - Space hardened material
  - Protective coatings/platings

Benefits

• Advanced materials:	20-30% weight savings Increased payload Greater range
• Low cost fabrication:	30% cost savings Reduced assembly time
• NDE/durable materials:	Increased reliability and vehicle life

ADVANCED MATERIALS, STRUCTURAL CONCEPTS AND FABRICATION METHODS FOR VEHICLES

MATERIALS

<u>LIGHT ALLOYS</u>

ALUMINUM-LITHIUM

TITANIUM

INTERMETALLICS

<u>METAL MATRIX COMPOSITES</u>

<u>POLYMER MATRIX COMPOSITES</u>

<u>ADVANCED TPS</u>

CERAMIC MATRIX COMPOSITES

CARBON-CARBON

SPRAY-ON FOAM

STRUCTURAL CONCEPTS

<u>INTEGRALLY STIFFENED SHELLS</u>

<u>GEODESIC SHELLS</u>

<u>HONEYCOMB SANDWICH</u>

<u>INTEGRAL STRUCTURE-CRYO TANKS</u>

<u>HYBRID STRUCTURE</u>

<u>(COMPOSITES//METAL)</u>

FABRICATION METHODS

<u>LIGHT ALLOYS</u>

SUPERPLASTIC FORMING

DIFUSSION BONDING

POWDER PROCESS

<u>METAL MATRIX COMPOSITES</u>

HOT PRESSING

JOINING

<u>POLYMER COMPOSITES</u>

TAPE PLACEMENT

WOVEN PLY LAY-UP

PULLTRUSION

RESIN INJECTION

THERMOFORMING

3000 STRUCTURES, MATERIALS & MANUFACTURING

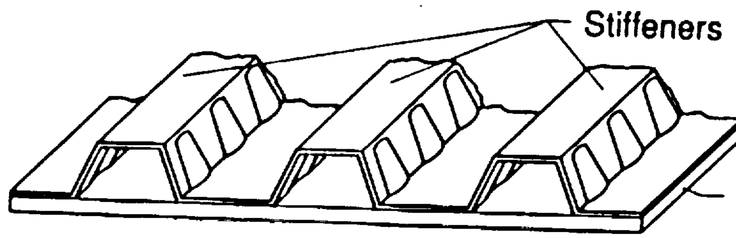
CURRENT PROGRAM ELEMENTS

	TECHNICAL AREA	TASK MANAGER
3101	ALS Materials & Processes Validation	AL / Bruce Pham
3102	Composite Intertank	MSFC / Jack Macpherson
3104	Built-Up Al-Li Structures for ALD	LaRC / John A. Wagner
3105	Expendable Structures	BAC / Brad Libbey
3106	Advanced Cryotanks	MMAG / Larry Loechel
3202	Low Cost TPS	MMAG / Eric Strauss

TERMINATED PROGRAM ELEMENTS

3107	Composite Structures	MMDA / Bruce Leonard
3201	Materials Development	LaRC / Alan H. Taylor
3203	Analysis Development	LaRC / Allan R. Wieting
3301	Test Demo. Components	DFRF / Michael DeAngelis

CANDIDATE MATERIALS AND JOINING PROCESSES FOR ALS SPF STIFFENED ALUMINUM TANKS



Materials

Conventional Al alloys

Skin
2219
2519

Stiffeners
7475
2036

Al-Li alloys

Skin
2090
Weldalite
8090

Stiffeners
2090
2090 + In
8090
Weldalite

Joining processes

Resistance spot welding
Resistance seam welding
Adhesive bonding
Weld bonding

1-4840-b-rD

POTENTIAL ELV STRUCTURES, MATERIALS, & MANUFACTURING COST-REDUCTION HARDWARE

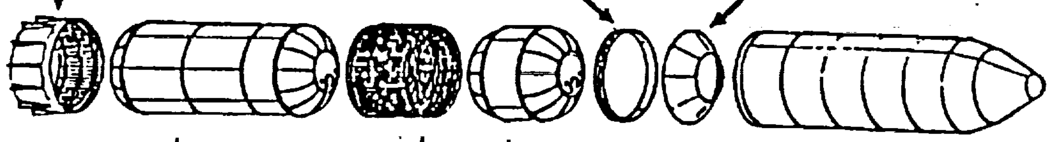
- 20-25% OF TOTAL ELV COST REDUCTION POTENTIAL IS IN STRUCTURES & MATERIALS

POTENTIAL COST REDUCTION

THRUST STRUCTURE: Gr/Ep CANDIDATE

FORWARD SKIRT: Gr/Ep CANDIDATE

PAYLOAD ADAPTER: Gr/Ep CANDIDATE



CRYOTANKS: ADVANCED ALUMINUMS

- INNOVATIVE DESIGN & PROCESSING TO COST
- AUTOMATED PROCESSING & INSPECTION
- REDUCED PART COUNT DESIGN
- ONE STEP TPS APPLICATION

INTERTANK: Gr/Ep

- DESIGN FEATURES
  - REDUCED PART COUNT DESIGN
  - AUTOMATED FABRICATION/ HANDLING/ASSEMBLY
  - IN-PROCESS INSPECTION/ CONTROL

SHROUD: Gr/Ep

- DESIGN FEATURES
  - REDUCED PART COUNT DESIGN
  - INNOVATIVE DESIGN & PROCESSING TO COST
  - ONE-STEP TPS APPLICATION
  - AUTOMATED FABRICATION/ HANDLING/ASSEMBLY
  - IN-PROCESS INSPECTION/ CONTROL

SPACE TRANSPORTATION

Technology Element

Vehicle Structures and Cryotanks

Technology Sub-Elements

Materials Characterization

Materials Processing

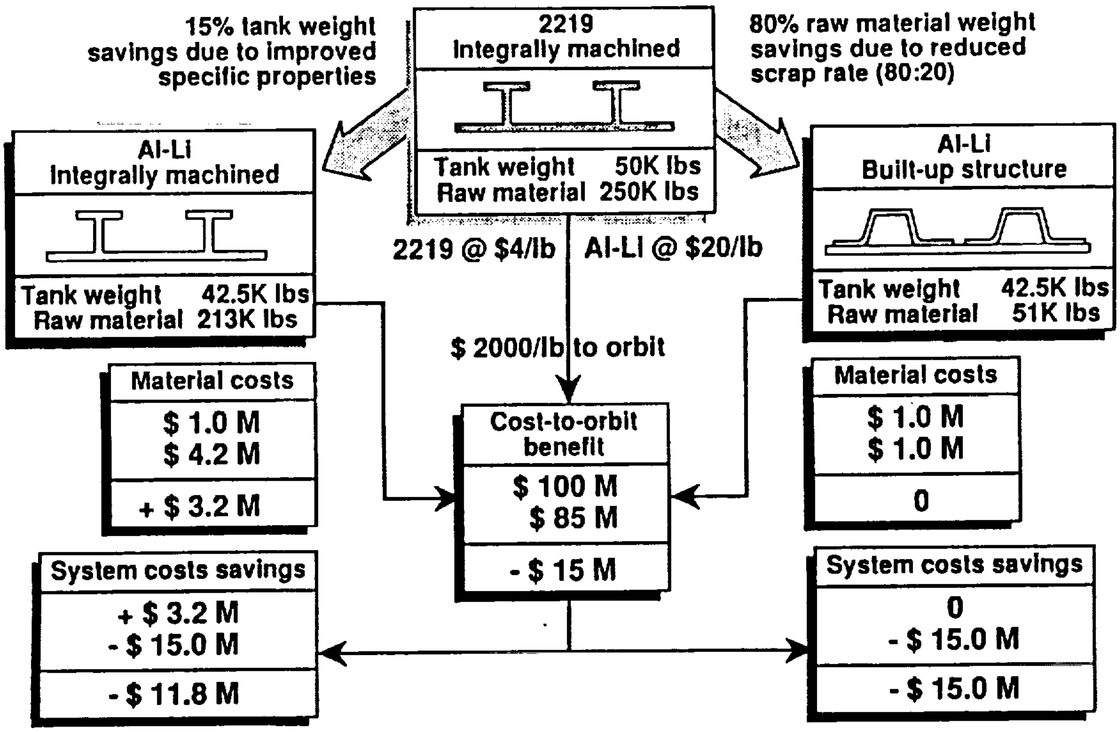
Environmental Effects and Durability

Cryogenic Insulation/TPS

Structural Design/Analysis

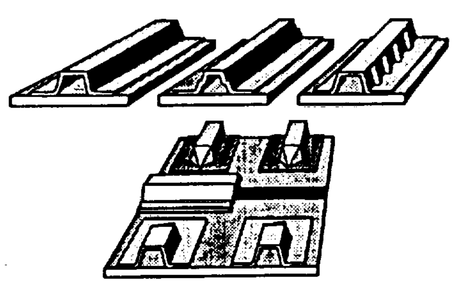
Sub-Component, Design, Fabrication, and Test

BENEFITS OF USING AL-LI ALLOYS FOR CRYOGENIC TANKS

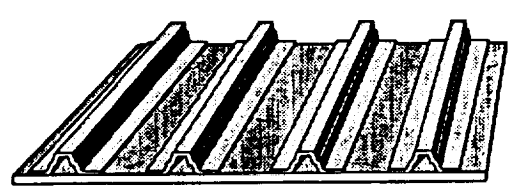


CRYOTANK AND DRY BAY SKIN STIFFENED FABRICATION TEST ELEMENTS

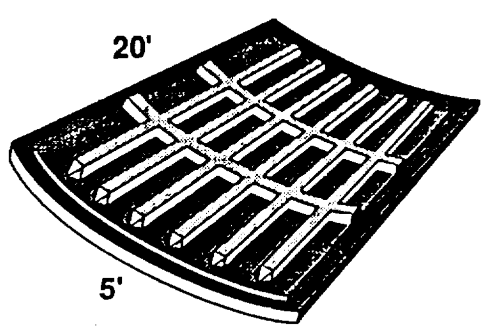
Crippling panels



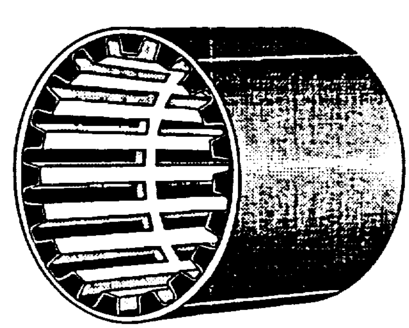
Column buckling panels



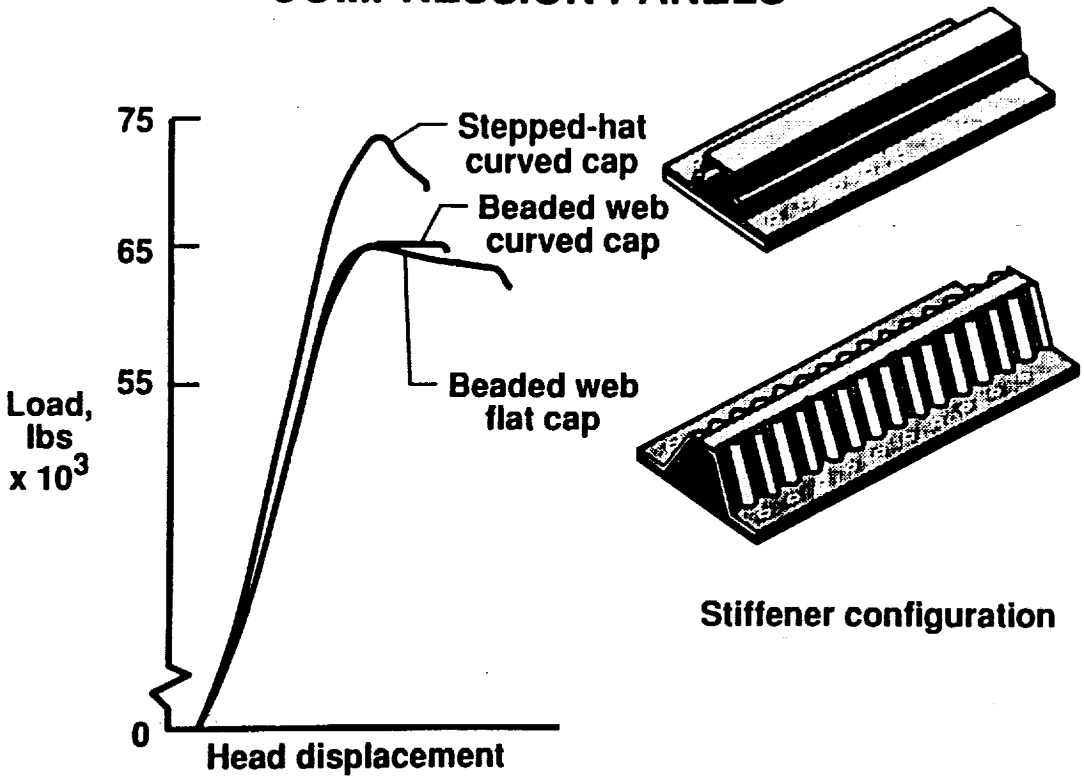
Barrel segment



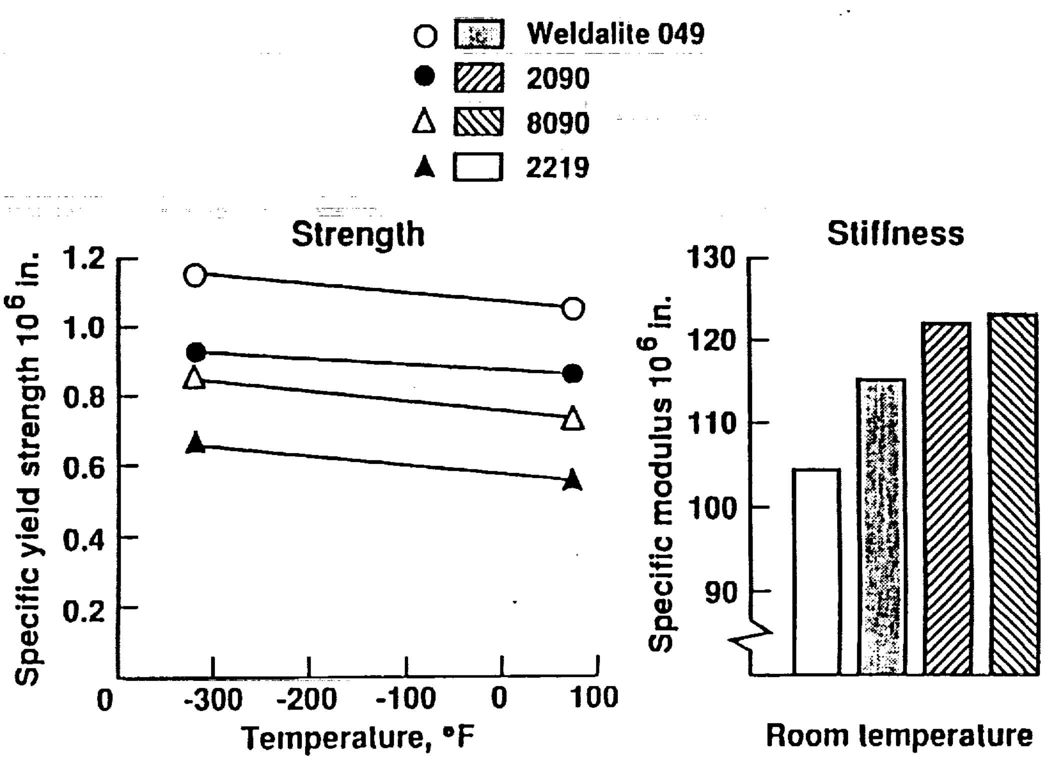
Sub-scale barrel section



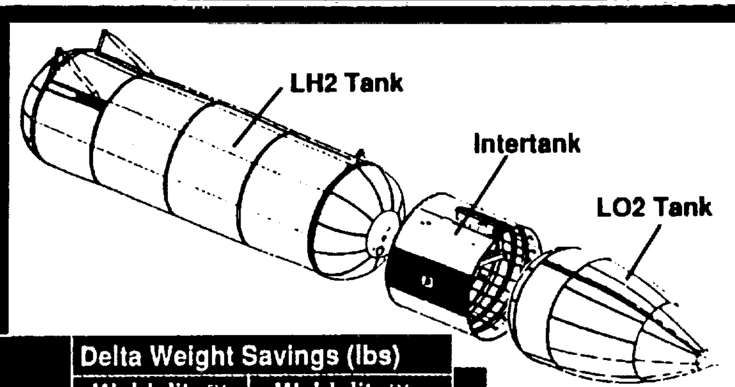
TEST RESULTS OF 2090-T6 (SPF)/2090-T8 Al-Li COMPRESSION PANELS



SPECIFIC PROPERTIES VERSUS TEMPERATURE FOR SELECTED AL ALLOYS IN T8 TEMPER



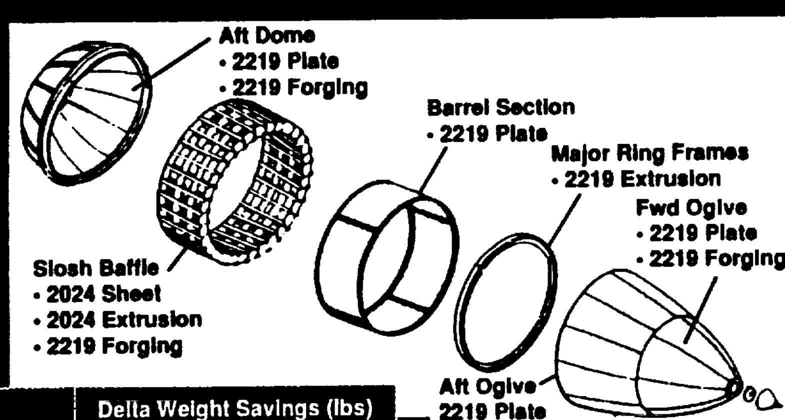
Weldalite™ External Tank



Element	LWT	Delta Weight Savings (lbs) Weldalite™ Substitution	Weldalite™ Resizing
LO2 Tank	11903	438	1780
Intertank	12166	409*	936**
LH2 Tank	27981	1003	4270
Misc.	13595	304	304
Total	65645	2154	7290

* 540 Additional Pounds Saved Using 2090 Alloy
**511 Additional Pounds Saved Using 2090 Alloy

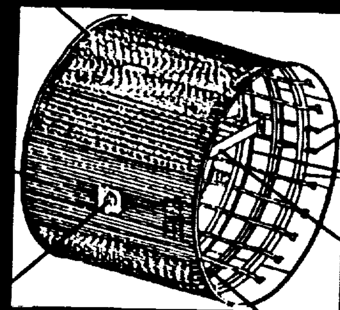
Weldalite™ LO2 Tank



Element	Current	Delta Weight Savings (lbs) Weldalite™ Substitution	Weldalite™ Resizing
Sheet/Plate	9944	378	1574
Extrusion	1516	50	166
Forging	265	10	40
Misc.	178	-	-
Total	11903	438	1780

93b.3500-4.6/28/90

Weldalite™ Intertank

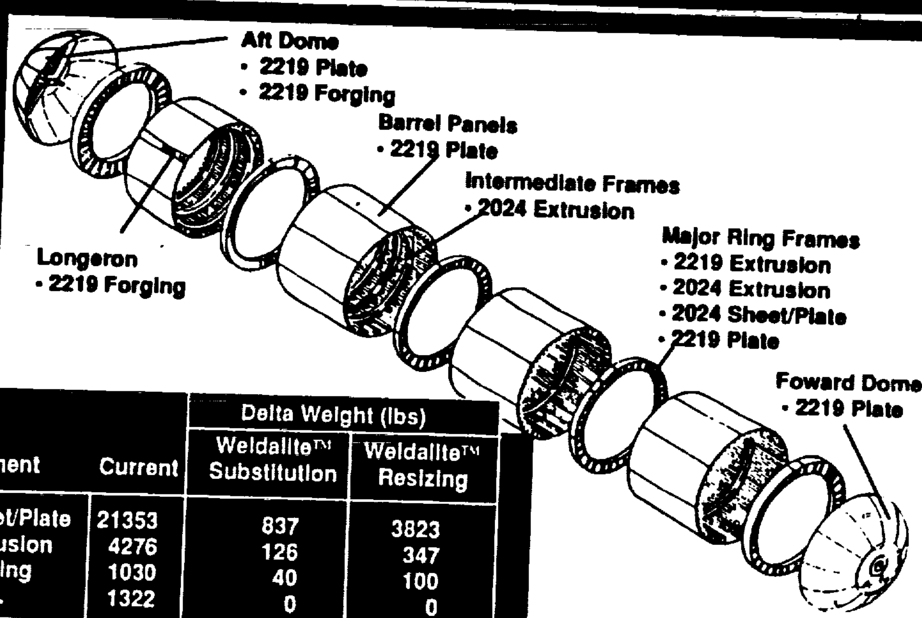


		Delta Weight Savings (lbs)	
Element	Current	Weldalite™ Substitution	Weldalite™ Resizing
Sheet/Plate	8132	309	652
Extrusion	2367	72	227
Forging	717	28	57
Misc.	950	-	-
Total	12166	409*	936**

*540 Additional Pounds Saved Using 2090 Alloy

**511 Additional Pounds Saved Using 2090 Alloy

Weldalite™ LH2 Tank

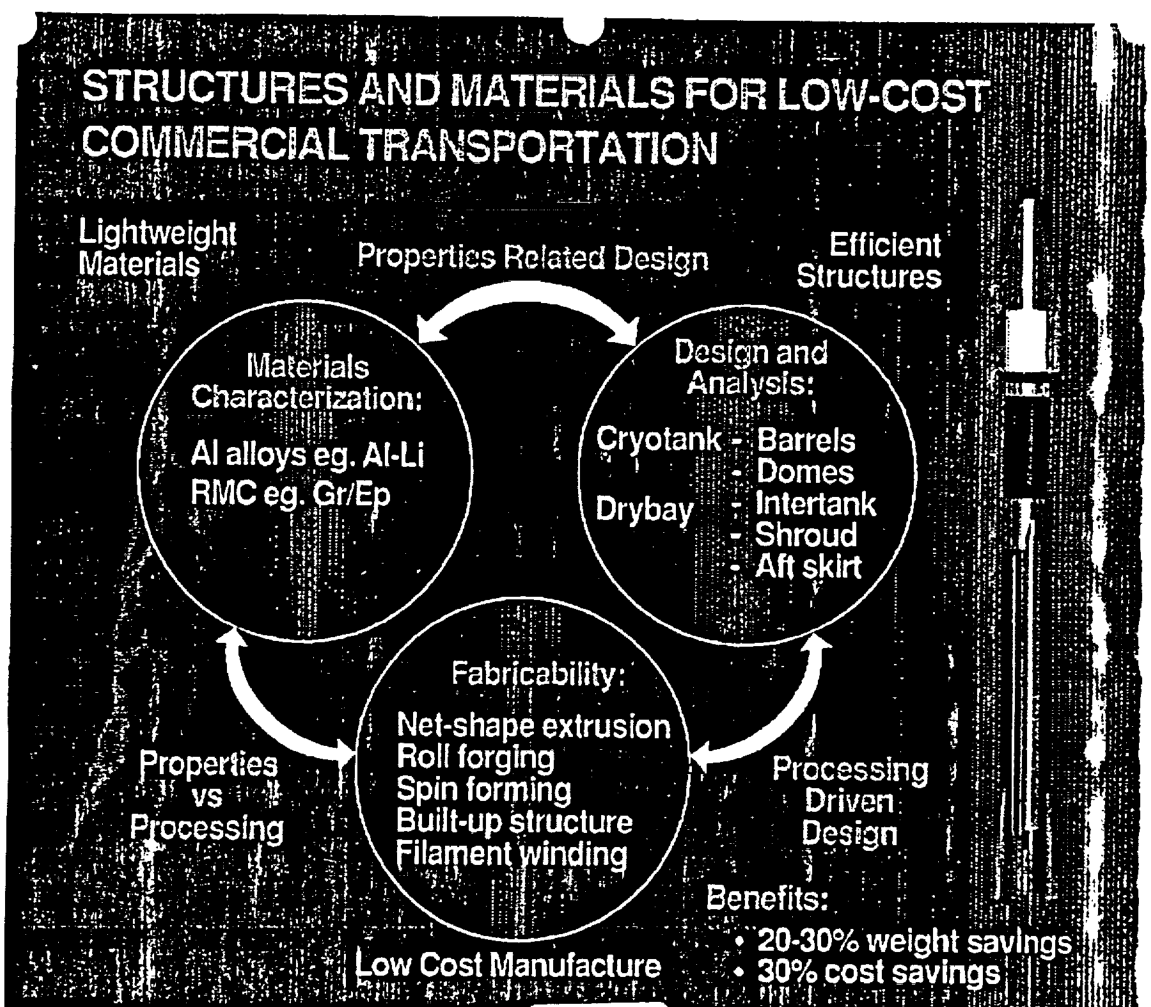


		Delta Weight (lbs)	
Element	Current	Weldalite™ Substitution	Weldalite™ Resizing
Sheet/Plate	21353	837	3823
Extrusion	4276	126	347
Forging	1030	40	100
Misc.	1322	0	0
Total	27981	1003	4270

VEHICLE STRUCTURES AND CRYOTANKS

Payoffs

- Significant reduction in structural weight (30-40%) improves payload capability and reduces operational cost
- Durable materials required for reusability, reduces in-space maintenance
- Improved cryogenic insulation reduces fuel requirements
- Development of these technologies is required for successful accomplishment of planned Lunar and Mars missions



INDUSTRY IDENTIFIED TECHNOLOGY INTERESTS FOR EXPENDABLE LAUNCH VEHICLES

MATERIALS & STRUCTURES

- Advanced Al-Li Cryotanks
- Isogrid Structures
- Common Dome Concepts
- Composite Intertank/Shroud Structures
- Composite Cryotanks
- LH2 Impermeable Tank Liner
- Improved Thermal Insulation
- Structural Loads/Response
- Tank Inspection/Testing
- Test Technology

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MANUFACTURING

- Al-Li Welding
- Automated Weld, Process Control, NDE
- Metal Forming Methods
- Advanced Composite Fabrication
- Joining Technology
- Automated Assembly
- In Process NDE
- Scale-Up/Size Limit

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TRANSPORTATION TECHNOLOGY

EARTH-TO-ORBIT TRANSPORTATION

LOW COST COMMERCIAL TRANSPORT

ELEMENT OBJECTIVE: DEVELOP AND VALIDATE TECHNOLOGIES WHICH SHOW PROMISE FOR SIGNIFICANT REDUCTION IN THE COST OF MANUFACTURING, CHECK-OUT AND OPERATION OF COMMERCIAL LAUNCH VEHICLES AND UPPER STAGES WHILE PROVIDING IMPROVEMENTS IN SYSTEM RELIABILITY AND AVAILABILITY (REDUCED TURN AROUND TIME)

TWO KEY AREAS OF CONSIDERATION

TECHNOLOGIES NOT BEING PURSUED IN OTHER ELEMENTS OF SPACE TECHNOLOGY PROGRAM

- TAILORED TO A COMMERCIAL NEED
- CURRENTLY BEING EVALUATED UNDER INDUSTRY SPONSORSHIP
- NASA CAPABILITIES/FACILITIES CAN CONTRIBUTE
- MAY PROVIDE ALTERNATE TECHNOLOGY TO MEET NASA NEEDS

APPLICATION (TRANSFER) OF NASA DEVELOPED TECHNOLOGIES TO MEET SPECIFIC COMMERCIAL NEED

- DEFINITION OF INDUSTRY-UNIQUE REQUIREMENTS
- VERIFICATION IN COMMERCIAL SYSTEM ENVIRONMENT (NASA OR INDUSTRY TEST BEDS)
- MAY PROVIDE EARLY VERIFICATION OF TECHNOLOGIES FOR NASA NEEDS

TRANSPORTATION TECHNOLOGY

EARTH-TO-ORBIT TRANSPORTATION

LOW COST COMMERCIAL TRANSPORT

GROUND RULES:

- INDUSTRY IDENTIFIED INTEREST
- TECHNOLOGY REQUIRES SIGNIFICANT LEVEL OF DEVELOPMENT AND/OR VALIDATION AT OR NEAR FULL SCALE PRIOR TO DEVELOPMENT (NOT FLIGHT HARDWARE DEVELOPMENT ACTIVITY)
- BENEFIT FROM NASA INVOLVEMENT (NOT JUST $)

IMPLEMENTATION APPROACHES:

- SPACE ACT AGREEMENT BETWEEN NASA CENTERS AND INDUSTRY (NO NASA FUNDING PROVIDED DIRECTLY TO INDUSTRY)
- JOINTLY PLANNED PROGRAMS UTILIZING NASA FUNDING AND INDUSTRY IR&D (NASA RESEARCH ANNOUNCEMENT TO SOLICIT COMPETITIVE APPROACHES)
- CONDUCT WORKSHOPS WITH INDUSTRY TO DISSEMINATE TECHNICAL DATA EARLY AND MORE EFFICIENTLY

Iransportation :hnology

Low-Cost Commercial Transport

Commercial Vehicle Structures & Materials

OBJECTIVES

- Programmatic

Develop and validate the structural design and material processing technologies that will provide weight and fab-rication cost savings of 30 to 40 percent. These objectives may be realized through the use of advanced metallics (AL-LI) and carbon-fiber composite materials fabricated by ad-vanced methods developed through this program.

- Technical
  - Develop critical processes analyses (Taguchi approach)
  - Develop the design for producibility methods required
  - Develop the low-cost processing / fabrication methods
  - Mature automated inspection and NDE methods
  - Execute subscale hardware design, fabrication, and test

TASK SCHEDULES/MILESTONES:

- Key Milestones:

1993 Select candidate Al-Li alloy for 14-ft. roll-forge tank.
1993 Select components and resin systems for composite material application.
1994 Roll-forge panels for material characterization tests.
1994 Complete auto-welding sensor investigation / eval.
1995 Demonstrate interactive graphics to control NC - machine tool path.
1995 Complete evaluation of extruded and built-up structure barrell panel products.
1996 Design and fabricate 14-ft. cryotank test article.
1996 Design, fabricate and test moderate size composite components built by low-cost processes.
1997 Verify closed-loop interactive graphics control of NC-machine operation.
1997 Test and evaluate demonstration 14-ft. Al-Li tank.
1997 Demonstrate automatic/robotic welding versatility.

RESOURCES

- 1993 $ 3.0 M
- 1994 $ 3.5 M
- 1995 $11.0 M
- 1996 $14,0 M
- 1997 $14.0 M

PARTICIPANTS

- Al-Li Cryotankage, Roll Forging, Spin-Forming — LaRC
- Built-Up Structure, Net Section Extrusion— LaRC
- Low-Cost Composites— MSFC
- Automated Inspection and NDE — MSFC
- Computer Integrated Manufactrue — MSFC
- Automated Welding — MSFC

LAUNCH VEHICLE HEALTH MONITORING

MDSSC

OBJECTIVE

- Develop and validate adaptive structures technology for application to health monitoring of launch vehicle structures
  - Develop/demonstrate the technology as applicable to launch vehicle structures and structural components
  - Validate technology for acceptance by launch vehicle programs

APPROACH

- Leverage extensive adaptive structures technology work performed to date for large space truss structures for use on launch vehicle structures
- Investigate cradle-to-grave structural health monitoring needs
- Coordinate development/validation effort with launch vehicle program to facilitate technology transfer to launch vehicle production
  - Perform feasibility studies based on actual requirements
  - Perform technology development for application to current and planned launch vehicles
  - Perform validation experiments required for program acceptance

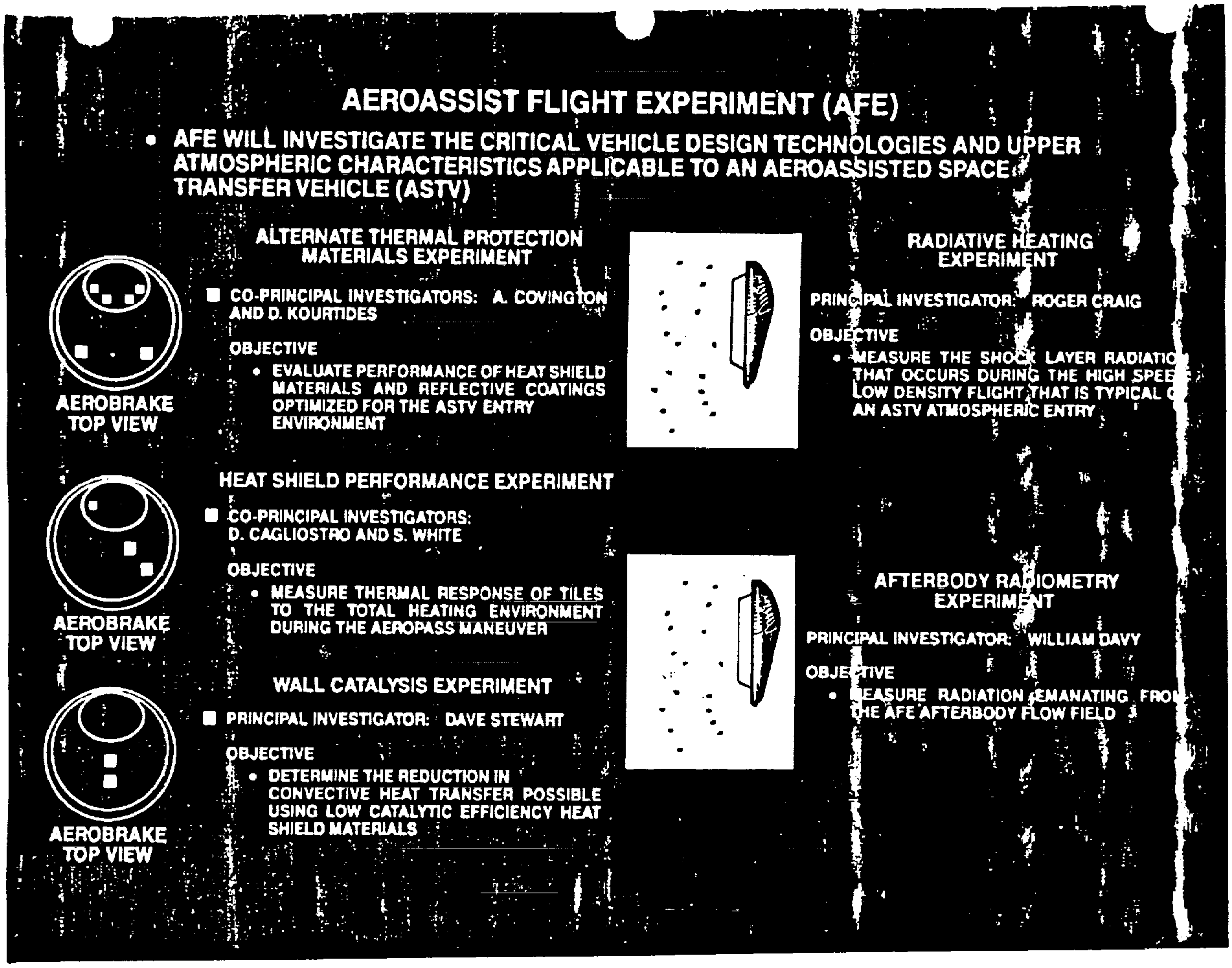
AEROBRAKE MATERIALS TECHNOLOGY DEVELOPMENT

Needs

- Mission/configuration/trajectory trade studies $\Rightarrow$ Environmental definition
- Integrated structures/materials concepts trade studies
- Candidate materials identification/development
- Materials screening in relevant environments
- Dynamic (arc jet) tests
- Mathematical models to predict service performance from ground-based test data
- Construct and verify performance of representative subelement assemblies
- Flight experiments to verify predictive capability
- Materials property design database
- Conduct materials performance/durability certification testing

Projected Results of Technology Development Program

- Validated materials performance and database for confident design and fabrication of aerobrake components for in-space assembly



AEROBRAKE MATERIALS

Aerobrake Performance Objectives

- Lifetime
  - Lunar missions: ≥ 7 flights
  - Mars missions: ≥ 2 flights
- Entry velocity range: 6 to 14 km/sec
- Maximum g-loads: 5 to 6
- Aerobrake/vehicle mass fraction: ≤ 15%

Basic Heatshield Requirements (configuration & trajectory dependent)

	Environment composition	Maximum radiation equilibrium temperature, °F	Aeropass time, sec.
Earth entry (Lunar mission)	air	2000-3000°F	100-300
Earth entry (Mars mission)	air	3500-4000°F	100-500
Mars entry	CO_2	2500-3500°F	700-1000

AEROBRAKE MATERIALS

General Materials Requirements

- High temperature capability
- High load bearing
- Lightweight
- Fully reusable (mission specific)
- Space durable in LEO/Lunar/interplanetary environments
- Material database as a function of temperature
- Verified performance capability in relevant service environments

AEROBRAKE MATERIALS TECHNOLOGY

Issue

- No validated aerobraking capability exists for SEI missions

Current Status

- Numerous aerobrake concepts/configurations/trajectories under consideration
    - Lifting brake
    - Raked cone
    - Ballute
    - Lifting body
- Mission environmental parameters not defined
    - Highly dependent on configuration/trajectory

AEROBRAKE

TWO STUDIES ON MARS AEROBRAKES:

LANGLEY RESEARCH CENTER - CONCEPTUAL DESIGN, IN-SPACE CONSTRUCTION

AMES RESEARCH CENTER - POINT DESIGN, FULLY ASSEMBLED

LANGLEY CONFIGURATION:

ASSUMED 557,000 LB VEHICLE VARIABLE SIZED AND PERFORMANCE (2-6 MAX. G)

AEROBRAKE DESGN: 2-D SPACE TRUSS COVERED BY HEXAGONAL PANELS

AMES CONFIGURATION:

160,000 LB & 320,000 LB VEHICLES, FIXED 88 FT DIA. AEROSHELL, MAX. G = 5

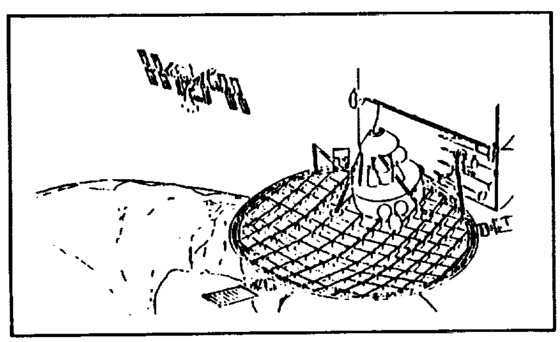
AEROBRAKE DESIGN: RIB STIFFENED PRESSURE SHELL

AEROBRAKES

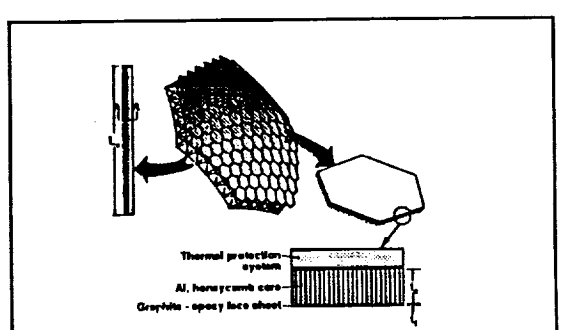
TWO GENERAL CLASSES:

RIGID CONSTRUCTION

1. RIB-STIFFENED PRESSURE SHELL:
   GROUND ASSEMBLED
   OR SPACE ASSEMBLED



2. SEGMENTED PANELS OVER A 2-D SPACE TRUSS:
   SPACE ASSEBMLED



DEPLOYABLE

3. FULLY DEPLOYABLE:
   GROUND ASSEMBLED

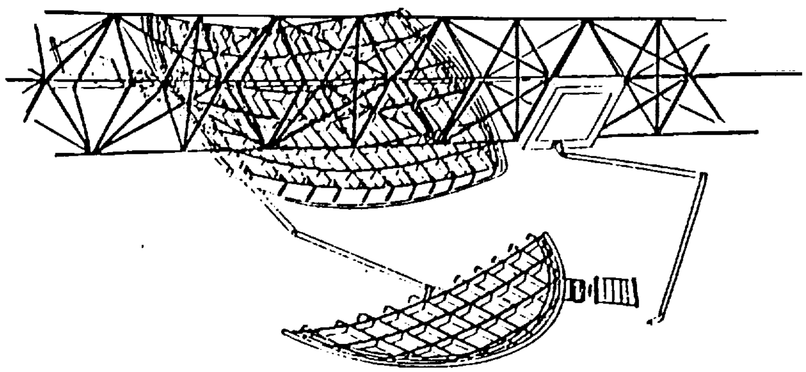
4. FABRIC BALUTE

AEROBRAKE SPACE CONSTRUCTION

RIB STIFFENED PRESSURE SHELL

PRO: A FEW LARGE PIECES (RADIAL SECTORS OR CHORDWIZE SLICES)
MOST CONSTRUCTION AND NTEGRATION DONE BEFORE LAUNCH

CON: LONG LINE JOINTS REQUIRING CLOSE ALIGNMENT AND MANY CONNECTIONS
STRUCTURE AND TPS NOT EASILY REPAIRED
INEFFICIENT PACKAGING DUE TO DOUBLY CURVED SEGMENTS

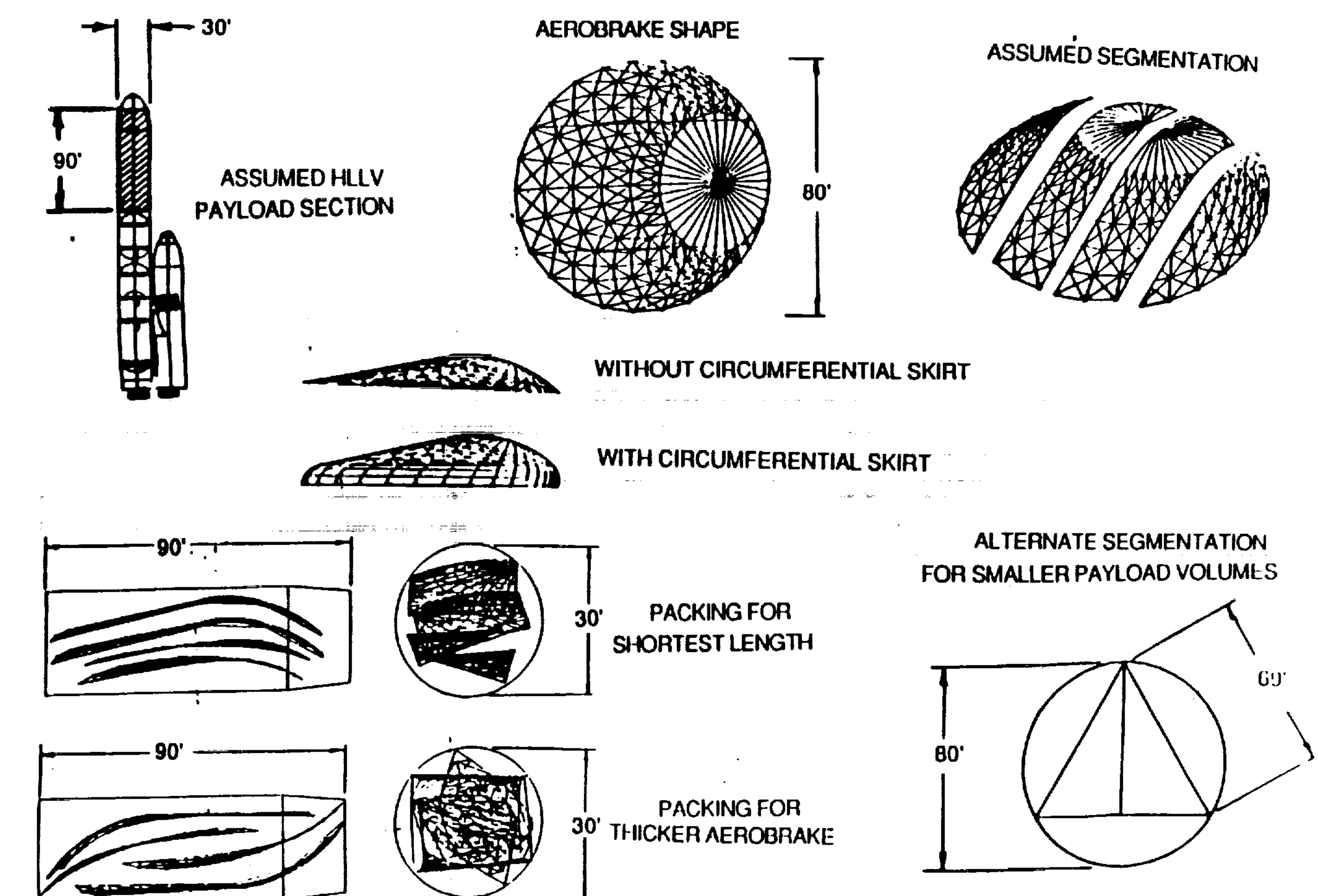


REQUIRES ADVANCES IN SPACE CONSTRUCTION TECHNOLOGY

MARSHALL SPACE FLIGHT CENTER

PATHFINDER
SEGMENTED AEROBRAKE PRELIMINARY PACKING STUDY

4/7/89

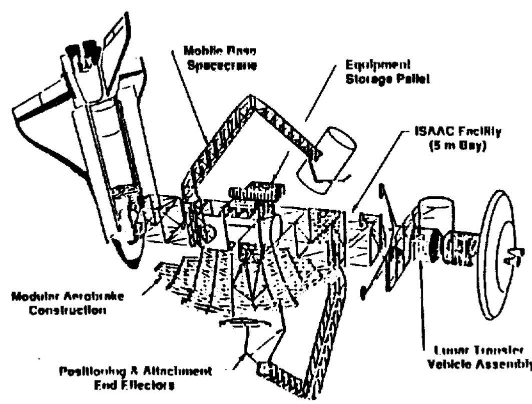


AEROBRAKE
SPACE CONSTRUCTION

2-D TRUSS WITH SEGMENTED PANELS

PRO:
- RELATIVELY SMALL EASY TO MANAGE PEICES
- SIMPLE OPERATIONS COMPATIBLE WITH ROBOTIC CONSTRUCTION
- A SPACE TRUSS IS THE MOST STRUCTURALLY EFFICIENT STRUTUCE
- EFFICIENT PACKAGING VOLUME
- STRUCTURE AND TPS EASILY REPAIRED

CON:
- MANY PARTS (SEVERAL HUNDRED)
- MANY JOINTS TO SEAL OVER THE PRESSURE SHELL



REQUIRES ADVANCES IN SPACE CONSTRUCTION

DEPLOYABLE AEROBRAKES

RIGID (OR "FLEXIBLE")

PRO:
- NO CONSTRUCTION REQUIRED

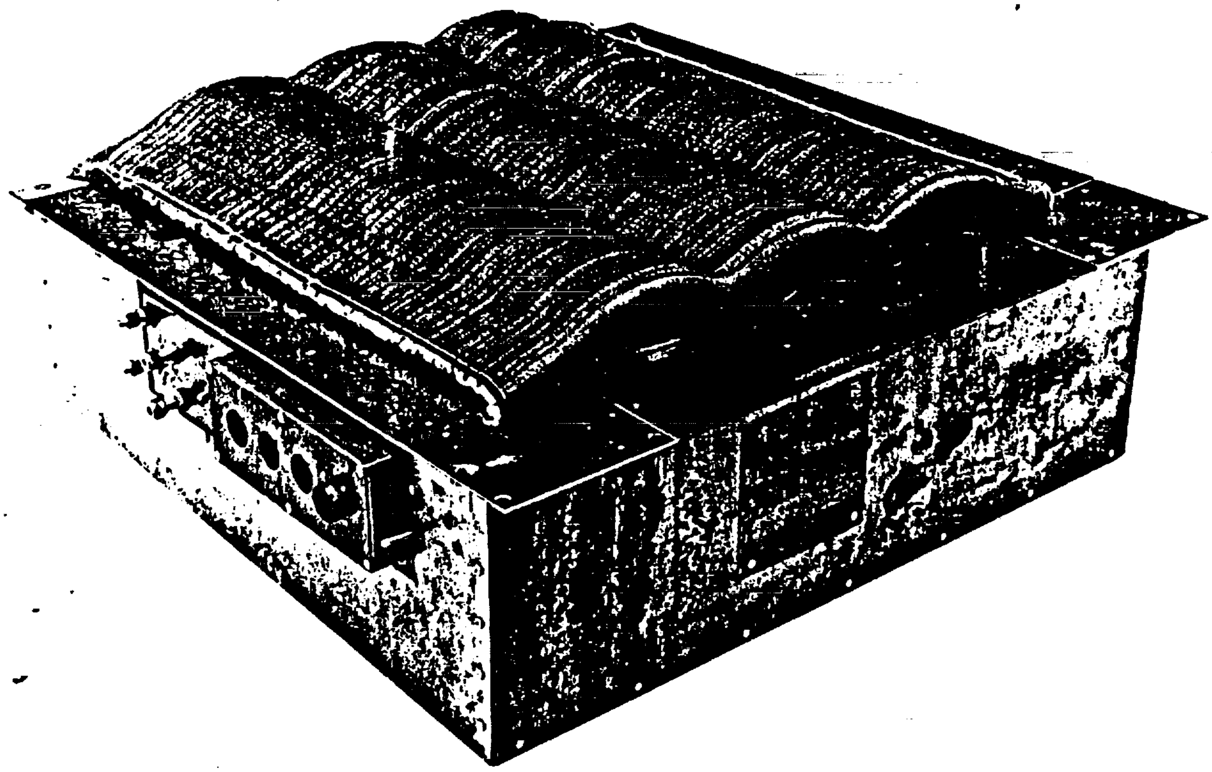
CON:
- DEPLOYABLES TEND TO BE HEAVIER THAN CONSTRUCTABLES OF COMPARABLE STRENGTH AND STIFFNESS (APPROX. 50% HEAVIER FOR A LIGHTWEIGHT PRECISION TRUSS)
- ISSUE WITH SEALING SEGMENT JOINTS
- INEFFICIENT PACKAGING RELATIVE TO A SPACE-CONSTRUCTED AEROBRAKE
- LIMITED IN SIZE (MORE THAN ONE FOLD GREATLY INCREASES COMPLEXITY AND DECREASES STRUCTURAL RELIABILITY)

FABRIC BALUTE:

PRO:
- VERY LIGHTWEIGHT
- VERY EFFICIENT PACKAGING (AND STOWING)

CON:
- VERY COMPLICATED DEPLOYMENT DYNAMICS
- HOT-SPOTTING ALONG GORE SEAMS
- MATERIALS ISSUES NOT SOLVED

WEAVING OF SILICA AND NICALON (SiC) FIBER
INTO 3-DIMENSIONAL BLANKET FOR BALLUTE APPLICATION DEMONSTRATED



AEROBRAKE

GENERAL CONCLUSIONS:

AEROBRAKE WEIGHT CAN BE LESS THAN 15% OF VEHICLE WEIGHT

MINIMAL WEIHGT SENSITIVE TO GOOD STRUCTURAL DESIGN

- BOTH STUDIES INDICATE WEIGHT CAN VARY BY A FACTOR OF 2-3
- LANGLEY STUDY INDICATES VOLUME WILL VARY SIMILAR TO STRUCTURE
- PRESSURE SHELL (SEGMENTED OR FULL) CAN BE 40%-50% OF TOTAL WEIGHT
- AMES STUDY INDICATES WEIGHT IS NOT SENSITIVE TO BALLISTIC COEFFICIENT

LANGLEY STUDY SHOWS A HEAVILY LOADED TRUSS CAN BE MADE WITH ONLY THREE DIFFERENT SIZE STRUCTURAL ELEMENTS WITH LITTLE EFFECT ON TOTAL WEIGHT OR VOLUME

LANGLEY STUDIES OF A PRECISION SEGMENTED REFLECTOR SIIMILAR TO THE AEROBRAKE INDICATE MANUAL IN-SPACE CONSTRUCTION WILL REQUIRE ABOUT 30 HRS.

88 FT. DIAMETER WITH AN 8-RING TRUSS AND 4-RINGS OF PANELS (4-M EACH)

TRUSS CONSTRUCTION = 14 HRS

PANEL INSTALLATION = 13 HRS

(TRUSS CONSTRUCTION BASED ON SIMULATED SSF TRUSS CONSTRUCTION IN MSFC NEUTRAL BOUYANCY FACILITY AND EXPERIENCE IN SPACE WITH EASE/ACESS)

N93-71845

SPACE RADIATION PROTECTION

S11-81
157521
P-11

Human Support Thrust

Exploration Technology Program

June 26, 1991

Edmund J. Conway
High Energy Science Branch
NASA Langley Research Center
804-864-1435

EXPLORATION TECHNOLOGY: HUMAN SUPPORT
SPACE RADIATION PROTECTION

Objectives

- Protect astronauts from space radiation while in transit and on lunar/Mars surface.
  - Effective, lightweight radiation shields.
  - Accurate predictions of radiation dose.
  - Reliable shield analyses for vehicles and systems.

Schedule

- 1992: Evaluate current analysis and testing capability to support lunar and Mars missions.
- 1993: Preliminary shielding concepts for a lunar habitat, pressurized rover, and MTV.
- 1994: Initial experimental evaluation of advanced shielding material concepts.
- 1995: Develop initial analytical/experimental data base on shielding materials and design concepts for a lunar outpost.
- 1997: Validated shielding analysis code to predict effectiveness against solar flares and cosmic rays to within 25 percent.
- 1998: Establish validated shielding materials data base for a lunar outpost (conventional materials and lunar regolith).

Resources ($M)

- 1991: 0.5
- 1992: 3.0
- 1993: 6.0
- 1994: 6.5
- 1995: 7.0
- 1996: 8.0

Participants

Lead: Langley Research Center

Other: Marshall Space Flight Center, Johnson Space Center } Users

DOE: Lawrence Berkeley Lab
Los Alamos National Lab
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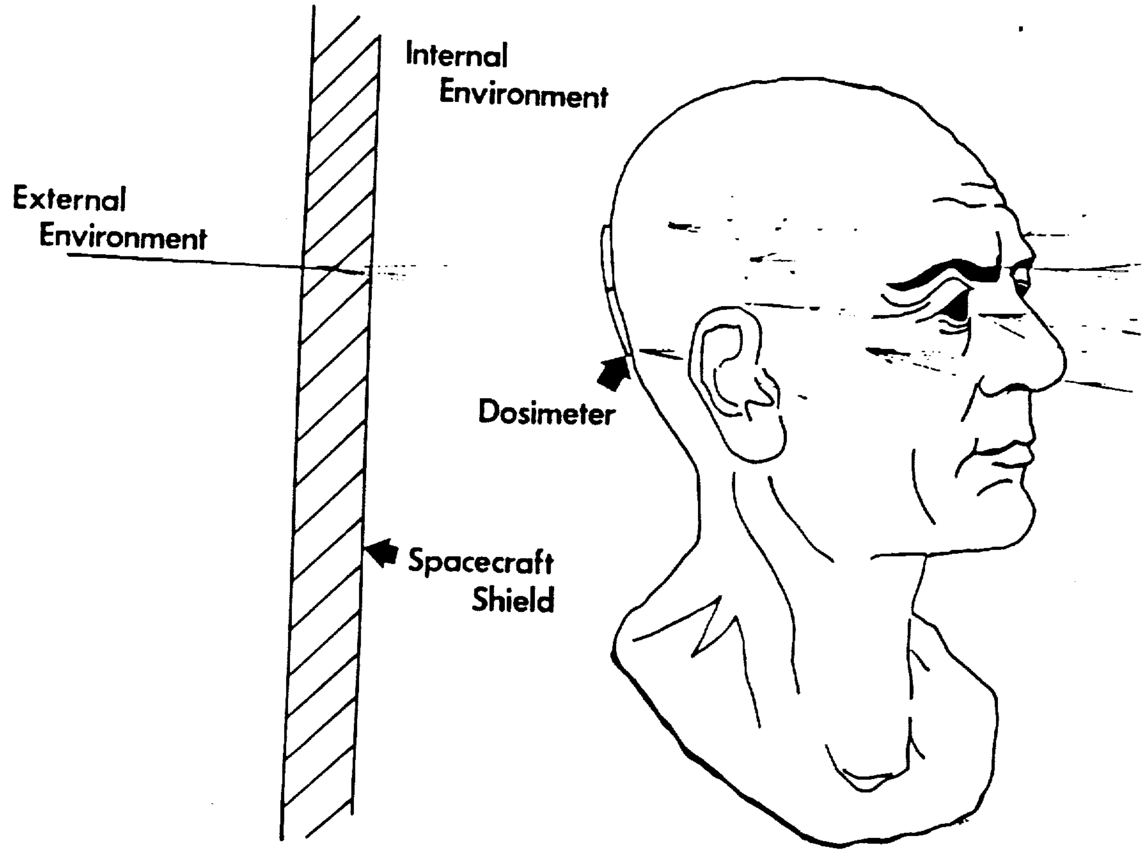
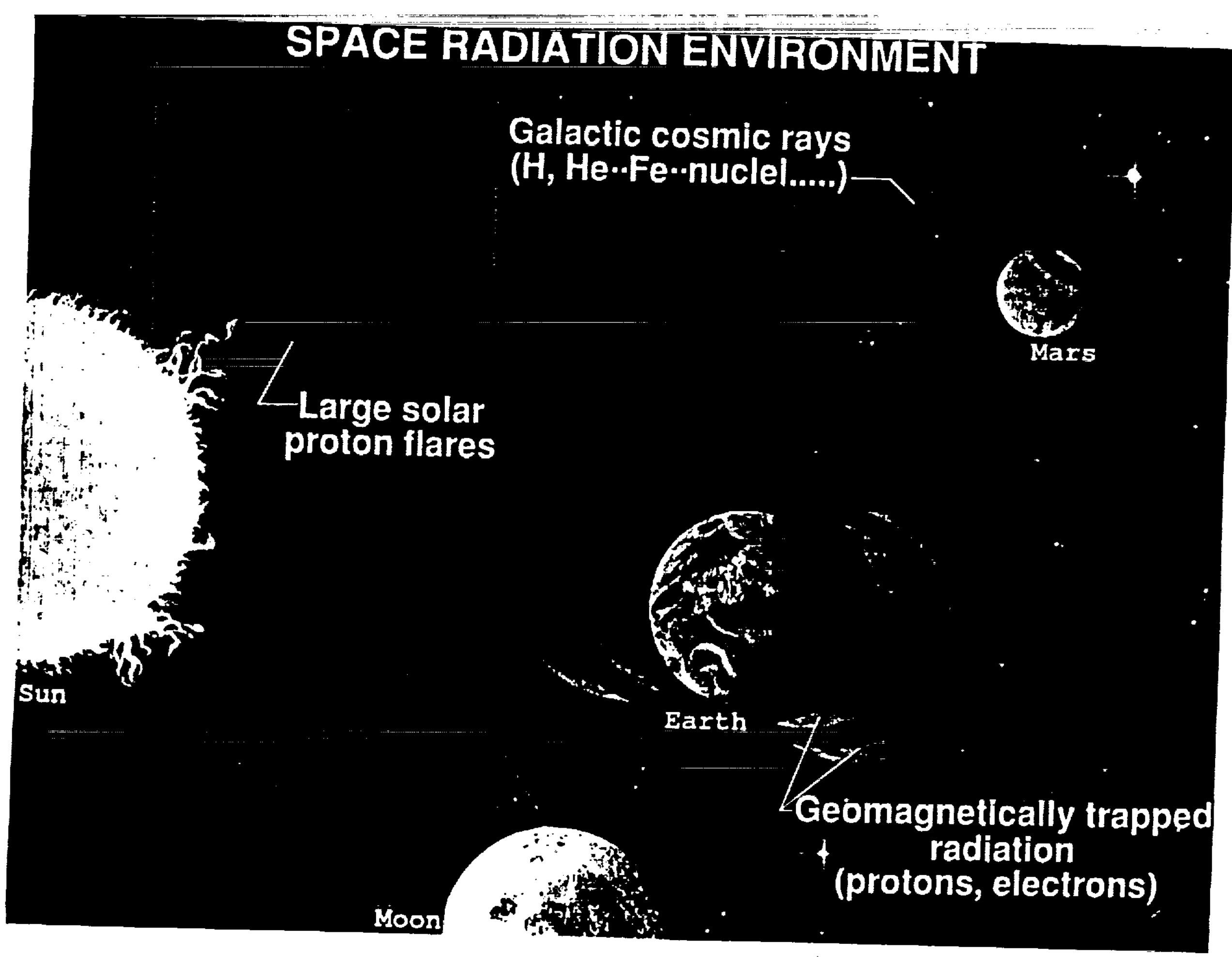
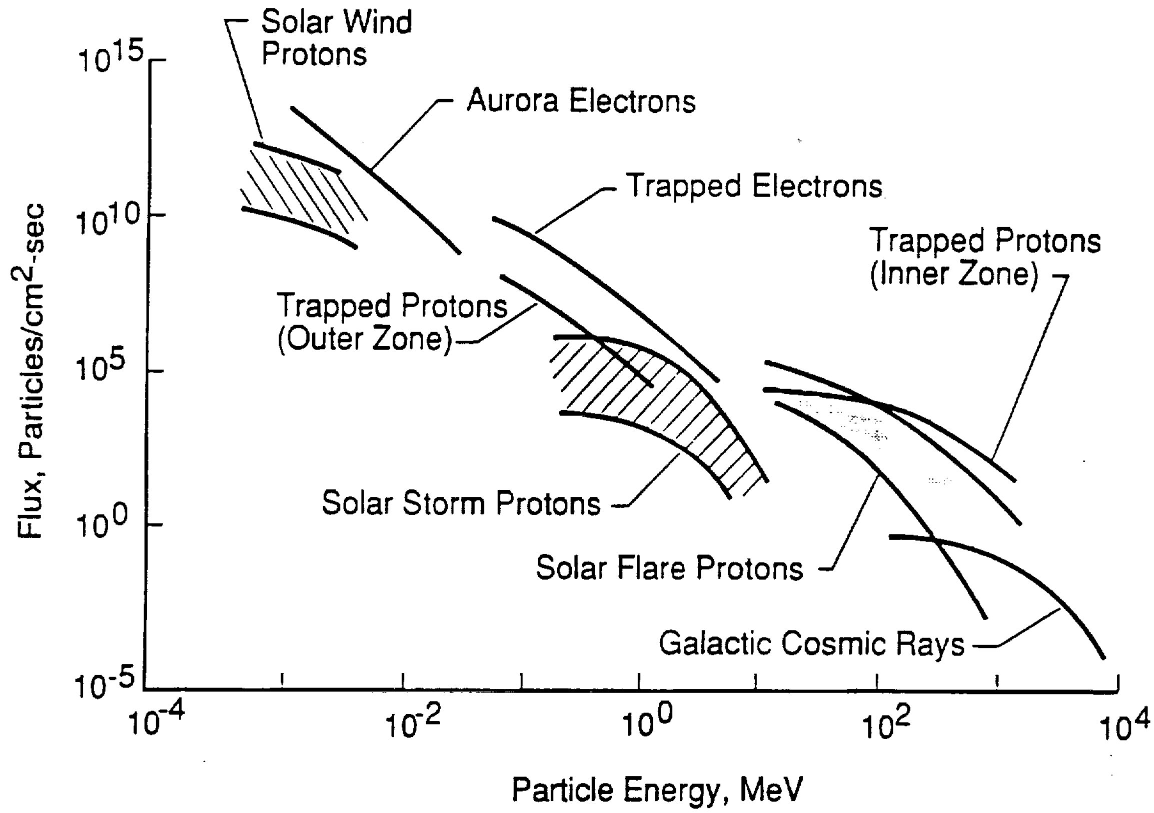

Internal Environment
External Environment
Dosimeter
Spacecraft Shield


SPACE RADIATION ENVIRONMENT
Galactic cosmic rays
(H, He··Fe··nuclei.....)
Mars
Large solar
proton flares
Sun
Earth
Geomagnetically trapped
radiation
(protons, electrons)
Moon



SPACE RADIATION ENVIRONMENT

Radiation	Description	Hazard	Avoidance Strategy
Trapped Radiation	Low-energy electrons and protons in Earth's magnetic field.	Long-duration exposure a hazard to life, equipment, and materials.	Rapid passage through Earth's radiation belts.
Solar Particle Events (SPE)	High-energy proton bursts.	Lethal aperiodic pulses of radiation.	Shields required for lunar outposts, rovers, and Mars piloted transfer vehicles (MTV)
Galactic Cosmic Rays (GCR)	High energy, heavy ions (≤ Fe) and light ions (p).	Continuous, low-intensity radiation. A heavy ion can be more than a thousand times as damaging as a proton.	Shields required for lunar outposts, rovers, and MTV.

EXPLORATION TECHNOLOGY: HUMAN SUPPORT
SPACE RADIATION PROTECTION

Technology Needs

- For crew safety and practical missions, exploration requires effective, low-mass shielding and accurate estimates of space radiation exposure.
  - Lunar (and Mars) habitat shielding
    - Regolith shield for surface habitat
    - Near zero dose within habitat
    - Accurate estimate of exposure behind the shield
  - Manned space transfer vehicle
    - Lightweight shields which minimize mass penalty to the mission and effective shielding from CGR and SPE
  - Strategies for minimizing exposure during EVA and rover operations
    - Safe haven shielding during a solar-particle event

TECHNOLOGY APPROACH

- Technology Development
  - Develop a materials data base to support radiation calculations and structural options.
  - Provide progressively improved accuracy validated computer codes to calculate exposure behind a shield.
  - Design shield concepts for spacecraft, habitats, and emergency shelters.
  - Build and laboratory-test technology breadboard shields.
  - Coordinate closely with radiation life science, policy, and user organizations.

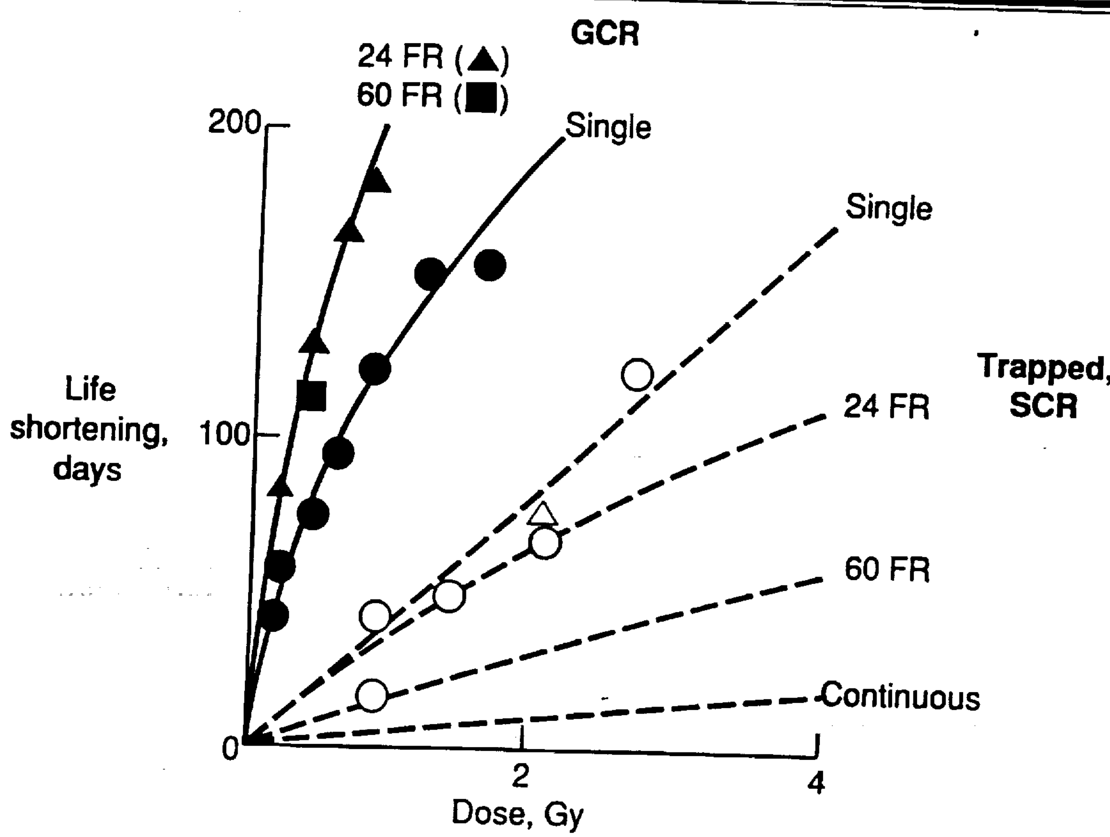
EXPLORATION TECHNOLOGY: HUMAN SUPPORT

SPACE RADIATION PROTECTION

STATE-OF-THE-ART ASSESSMENT

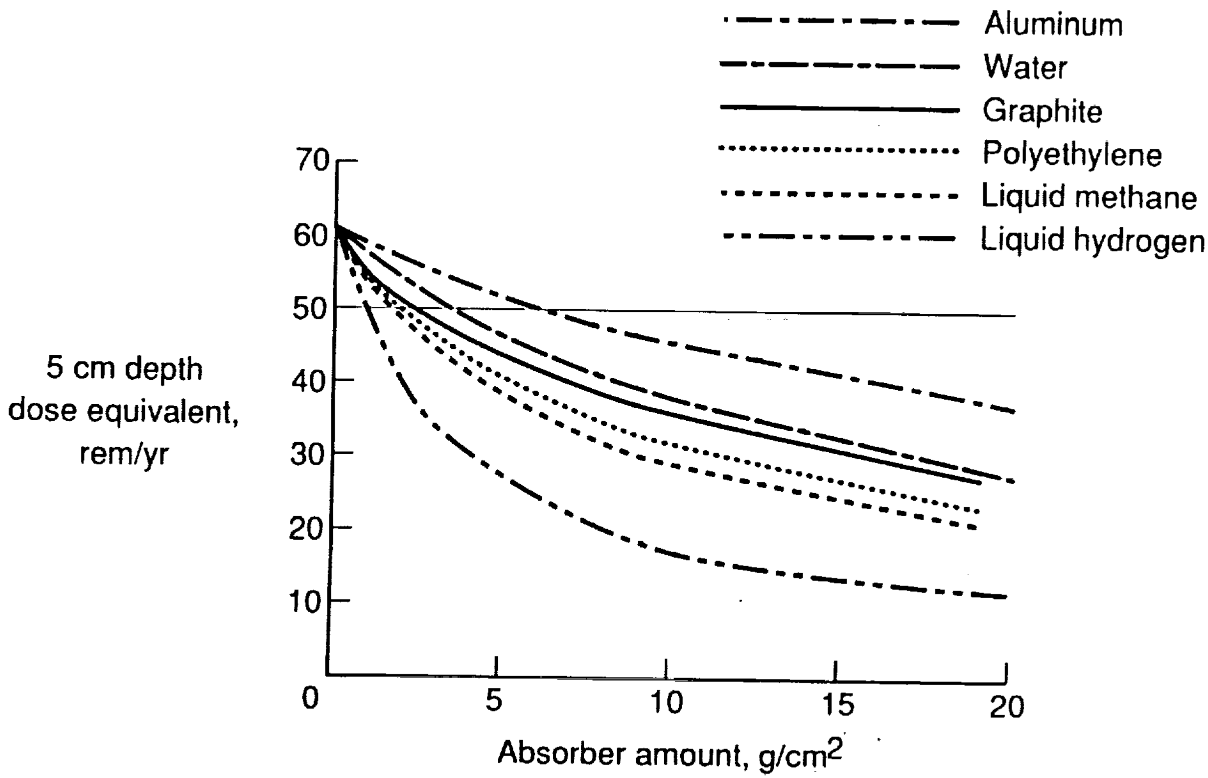
- General Assessment: GCR is the major threat to a shielded crew, but shielding concepts and technology are only at technology maturity level of 1-2.
- Detailed Assessment:
    - State-of-the-art shields are Al for spacecraft and regolith for surface habitats.
    - GCR estimates are only accurate to a factor of 2 in exposure and 10 in shield mass.
        - Manned Mars transfer vehicle shield mass estimates range from 80 to 800 tonnes.
        - Theory is incomplete, and few valid measured cross sections exist.
    - SPE, the most dangerous radiation component to an unshielded crew, requires a storm-shelter approach.
        - Theory adequately accurate with existing cross sections data base.
    - Trapped radiation will provide only a small dose to the crew during fast passage through the Earth's radiation belts.
        - Proton and electron components are treated adequately in available codes.
    - Two approaches to GCR interaction and transport calculations exist: Monte Carlo and deterministic. The accuracies can be equivalent, but the deterministic approach is computationally efficient and an emerging engineering tool.
    - Radiation shielding complements OSSA programs on radiation biology and the space radiation environment.

COMPLEX BIOLOGICAL FACTORS



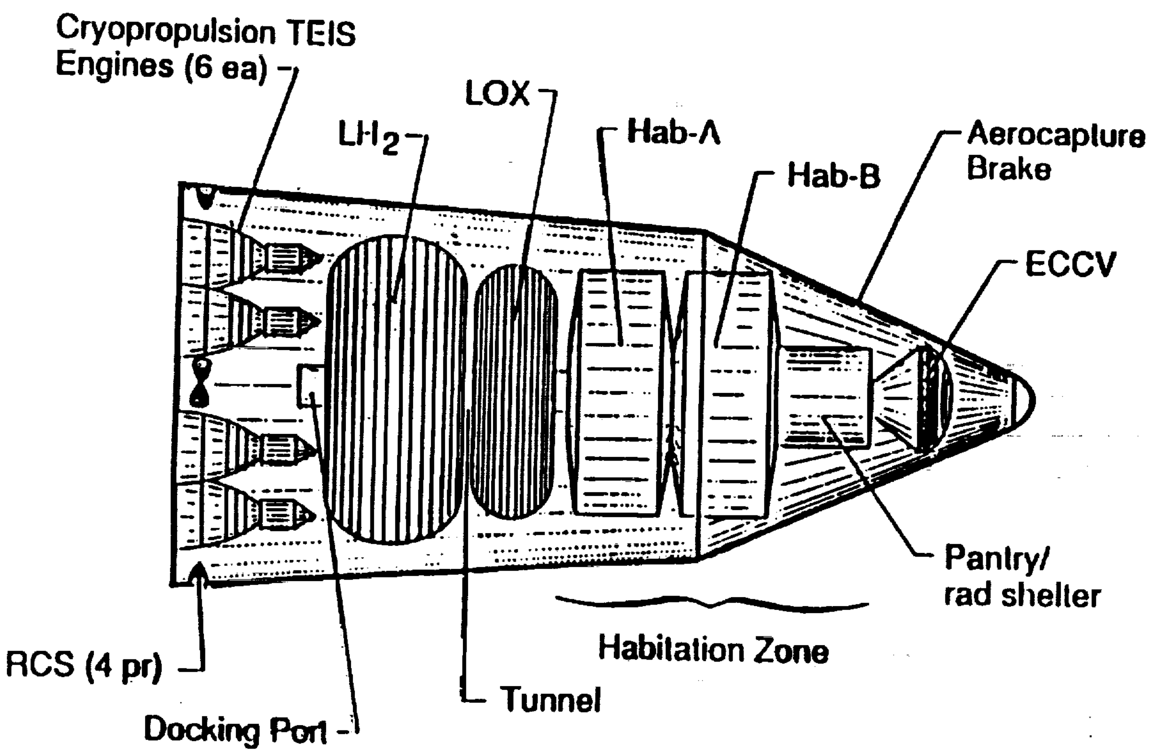
GALACTIC COSMIC RAYS - SOLAR MINIMUM

(Depth vs. Dose Functions for Selected Materials)

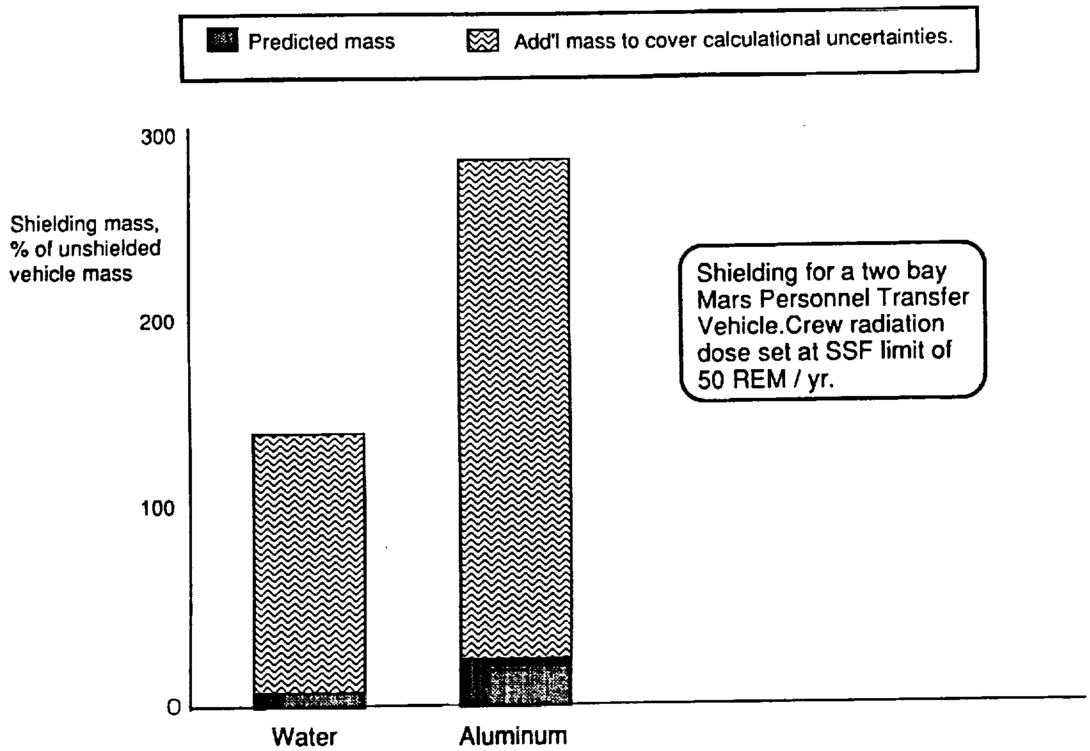


MARS PILOTED VEHICLE (BICONIC AEROBRAKE)

Martin Marietta Concept



LaRC GCR Shield Mass Predictions



- The mass of radiation shielding will be a significant fraction of the total spacecraft mass.
- Current uncertainty would result in highly inefficient design.

SPACE RADIATION PROTECTION

TRANSFER VEHICLES

Sources of Shielding

Inherent Structure

— 50 percent of Apollo capsule (solid angle) had the equivalent of 10 gm/cm^2 Al (shielding effectiveness ranged from 1.75 gm/cm^2 to 212 gm/cm^2).

— Skylab wall was approximately 1 gm/cm^2 of Al, but shielding was equivalent to 10-15 gm/cm^2 in parts of the workshop.

— Spacelab effective shielding ranges from 1 gm/cm^2 to 20 gm/cm^2

Vehicle Systems: Fuel, aerobrake, cargo, etc.

Additional shielding material

Issues

Uncertain shielding effectiveness - very nonlinear

Shielding can weigh a few tens to several hundred tonnes

Large solar flare require over 50 gm/cm^2 Al (or 30 gm/cm2 water)

SPACE RADIATION PROTECTION

TRANSFER VEHICLES

For Reference

Stiffened pressure shell with additional water shielding

Stiffened shell structure equivalent to about 0.32 cm (.125 inches)

Areal density: 0.85 g/cm^2 (1.75 lb/sq ft)

Water shield 3.5 g/cm^2 (7.2 lb/sq ft) plus tanks

Total spacecraft wall areal density: 4.4 g/cm^2 (9.0 lb sq ft)

Lightweight integral structural shielding

Areal density approximately 1.9 g/cm^2 (3.8 lb/sq ft)

No parasitic weight

Total spacecraft wall areal density: 1.9 g/cm^2 (3.8 lb/sq ft)

Use of lightweight polymer matrix composites (PMC) in place of aluminum throughout a space vehicle may provide radiation shielding without any weight penalty - (PMC 20 percent - 30 percent lighter than aluminum for comparable structural performance).

Large uncertainty of calculated and allowable dose - water is a good reference to estimate shielding-weight sensitivity.

EXPLORATION TECHNOLOGY: HUMAN SUPPORT
SPACE RADIATION PROTECTION

OTHER EFFORTS

- OSSA supports (a) research leading to improved understanding of the space radiation environment and (b) GCR and SPE radiobiology.
- DOD continues to support weapons effects research, primarily on moderate energy neutrons.
  - Both in-space and in-atmosphere releases.
- A large industry/university/National Lab base exists for calculating fission and fusion radiation.
  - Approximately 95 percent of our nation's radiation measurement and calculational capabilities supports DOD/DOE moderate energy nuclear programs.
- NIST maintains an electron-irradiation standards development program.
  - Industrial applications, such as sterilization of food.

EXPLORATION TECHNOLOGY: HUMAN SUPPORT
SPACE RADIATION PROTECTION

Performance Objective

To limit mission shield mass penalty to no more than a 50-percent (~ 1 g/cm^2) increase in wall aerial density.

APPROXIMATE SHIELDING FOR 50 REM/YR DOSE LIMIT FOR GCR

Material	Thickness (cm)	Aerial Density (g/cm^2)	STV Shield Mass (STV = SSF Habitat)* Tonnes
Hydrogen	13.7	1.0	1.9
Methane	3.6	1.5	2.8
Polyethylene	1.7	1.7	3.2
Graphite	0.9 - 1.1	2.0 - 2.4	3.7 - 4.5
Water	3.6	3.6	6.7
Aluminum	2.3	6.1	11.3
Polyethylene/ GCR composite, (estimated from constituents)	1.2	1.9	3.5

* Reference: Mass 15.9 tonnes
Surface area 186 m^2

EXPLORATION TECHNOLOGY: HUMAN SUPPORT
SPACE RADIATION PROTECTION

Current Program (FY 1992)

- Materials Data Base:
  - Initiating study of polymers for multilayer radiation shields.
  - Preparing for initial particle accelerator measurements at LBL in 1992.
- Analytical Code Development:
  - Assessing uncertainty in transported GCR fluence due to uncertainties in fragmentation cross sections.
  - Improving nuclear fragmentation models.
- Shield Design:
  - Defining shield concepts for lunar habitat, manned rover, and space transfer vehicles.
- Shield Breadboard

EXPLORATION TECHNOLOGY: HUMAN SUPPORT
SPACE RADIATION PROTECTION

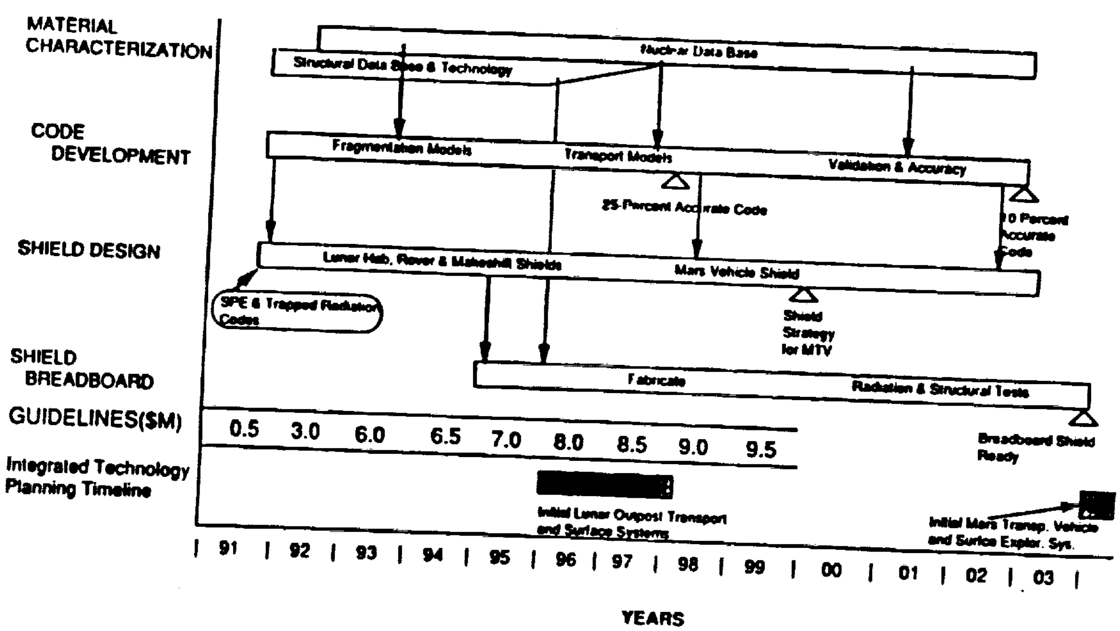
Current Program (Continued)

- Related Code E Life Science Program
  - Accelerator experiments
    - Fluence measurements in tissue and equivalent materials (e.g., H_2O)
  - Exposure codes
    - Improvements for radiation transport in tissue.
    - Applications of codes to Lifesat, radiobiology experiments, and human exposure.

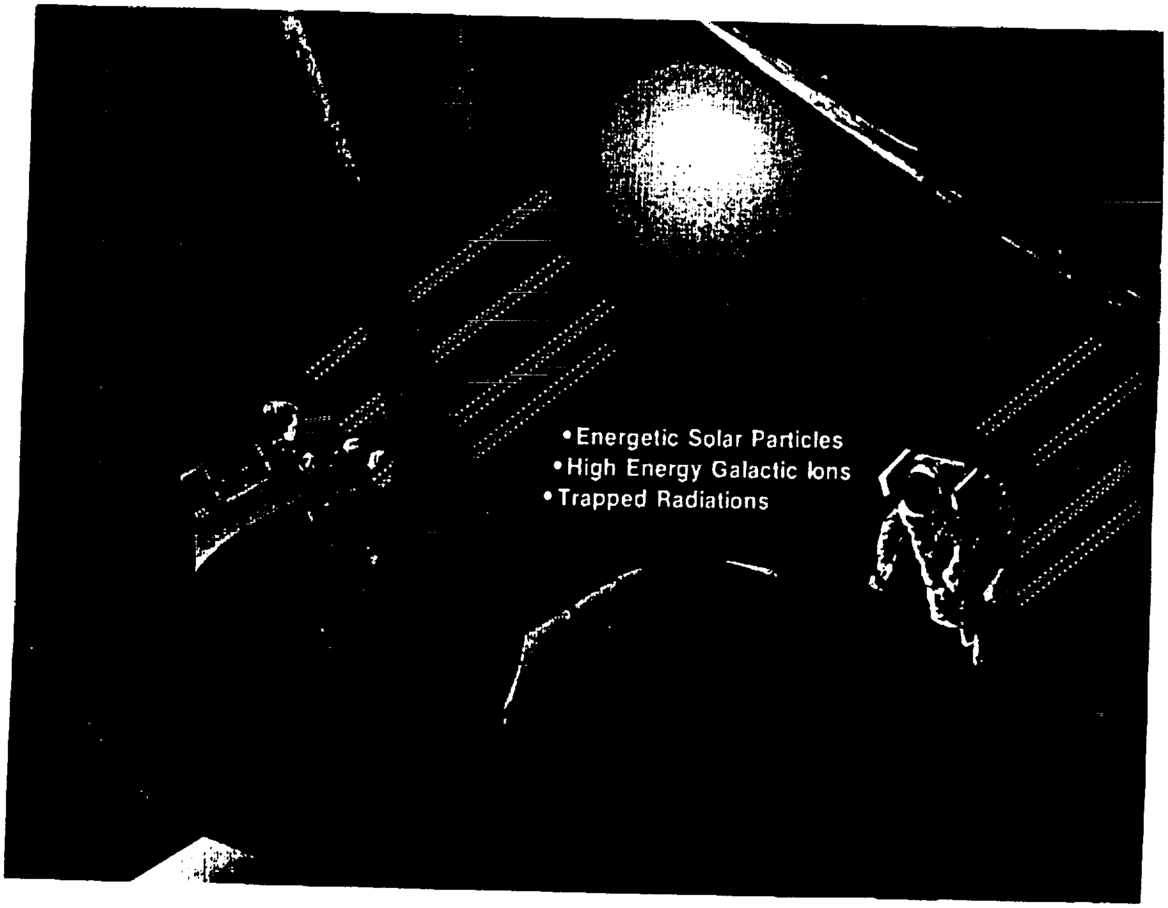
EXPOLRATION TECHNOLOGY: HUMAN SUPPORT

SPACE RADIATION PROTECTION

Schedule and Roadmap



Space Radiation Environment



SPACE RADIATION PROTECTION SUMMARY

Importance: Crews on deep-space missions face radiation hazards ranging from radiation sickness and death to increased likelihood of cancer.

Goal: To develop the technology for effective, low-mass radiation shields for spacecraft and surface systems.

Resources:

FY	91	92	93	94	95	96
$M	0.5	3.0	6.0	6.5	7.0	8.0

More than 75 percent of the funds pay for accurate radiation data.

Elements: Materials Data Base
Advanced Analytical Code Development
Shielding Concepts
Laboratory Breadboards

Coordination: Life Science; Radiobiology
Space Physics; Space Environment
MSFC and JSC; Users
DOE National Labs; Colleagues

NASA

Technology Program

N93-71846

157522

p. 21

INTEGRATED TECHNOLOGY PLAN
FOR THE CIVIL SPACE PROGRAM

IN-SITU RESOURCE UTILIZATION (ISRU)

SURFACE SYSTEMS PROGRAM AREA
OF THE
EXPLORATION TECHNOLOGY PROGRAM

David S. McKay
NASA Johnson Space Center
June 27, 1991

Mission Science and Technology Office

D. McKay 6/26/91 p. 1

NASA

Utilization of Lunar and Mars Resources

- What are these resources?
- Why are they useful?
- What is our overall strategy?
- What is our technology plan?
- What are we doing now?
- What else is going on related to resource utilization?
- What happens next?

Mission Science and Technology Office

D. McKay 6/26/91 p. 2

NASA

LUNAR RESOURCES

Each cubic meter of lunar regolith:

APPROXIMATE MASS: LOOSE - 1500 kg (1.5 gm/cc) from 0 to 30 cm
COMPACTED - 1800 kg (1.8 gm/cc) from 30 to 60 cm

Elemental Composition *

OXYGEN	
SILICON	420 kg
IRON	200 kg
ALUMINUM	50-150 kg
MAGNESIUM	50-120 kg
TITANIUM	35-70 kg
CALCIUM	30-60 kg
	70-100 kg

Minerals are silicates and oxides. Mineral forms are similar to terrestrial minerals, but compositions are slightly different.

Major phases in soil:

1. Rock fragments (basalts, anorthosites, and fragmental breccias)
2. Impact-produced glass (mainly agglutinates)
3. Mineral fragments

VOLATILES

HYDROGEN		
CARBON	50-100 gm	(average closer to 50 gm; some soils >100 gm)
NITROGEN	100 gm	(mostly in CO and CO2)
HELIUM	100 gm	(distribution parallels carbon)
	20 gm	(variable; approximately 10 mg Helium-3)

* Composition varies with soil location - mare or highlands - and age

Mission Science and Technology Office

NASA

Lunar Resources

A Lunch for two:

In each cubic meter of typical lunar regolith there is enough oxygen, hydrogen, carbon, nitrogen, and other elements to make a lunch for two people including:

Two cheese sandwiches

Two 12 ounce canned drinks

Two plums for dessert

(Larry Haskin, Department of Chemistry
Washington University, St. Louis)

Extracting the elements and producing the lunch is a technology problem--but the raw materials are there

Mission Science and Technology Office

NASA

Utilization of Lunar and Mars Resources

- What are these resources?
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- What happens next?

Mission Science and Technology Office

NASA

Oxygen: an example of cost savings

- Oxygen needed primarily for propellant
- Assume lunar lander will use ~25 tons per round trip flight
- Cost to bring oxygen from earth may be on the order of $30 million/ ton
- Mass of oxygen plant and mining equipment may be less than one year's oxygen production mass
- Payoff from oxygen plant may be significant: for two lander round trips a year, direct transportation savings should be $1.5 billion (after first year)
- Over a 21 year plant life, potential savings of $30 billion dollars, just for lander operation; more if oxygen used for other parts of transportation system and life support

Mission Science and Technology Office

D McKay 6/26/91 p 6

NASA

Utilization of Lunar and Mars Resources

- What are these resources?
- Why are they useful?
- What is our overall strategy?
- What is our technology plan?
- What are we doing now?
- What else is going on related to resource utilization?
- What happens next?

NASA

Overall Strategy

- Identify useful products and and relate to architectures using Stafford Synthesis Group Report as first-order guide
- Evaluate lunar/Mars geologic data and identify further exploration requirements for resources
- Assess state-of-the-art technology for resource utilization
- Identify new technology requirements and design development program
- Iterate and periodically update product needs, resource survey data, and technology development as an interrelated set

NASA

In Space Resource Utilization (ISRU)

- What are these resources?
- Why are they useful?
- What is our overall strategy?
- What is our technology plan?
- What are we doing now?
- What else is going on related to resource utilization?
- What happens next?

Mission Science and Technology Office

D. McKay: 8/28/91 p 9

NASA

In Space Resource Utilization (ISRU)

TECHNOLOGY NEEDS

LUNAR OUTPOST

- Methods for extracting useful materials from regolith
  - Oxygen
  - Metals (e. g. Iron, Magnesium, Titanium, Aluminum, Silicon)
  - Implanted gasses (e. g. Hydrogen, Nitrogen Helium, Carbon Dioxide)
  - Construction materials (e. g. Ceramics, Glasses)
- Mining Methods (maximize automation/robotics)
- Production Plant Concepts
- Fabrication methods (e. g. Casting, Sintering, Metal Forming, Vapor Deposition)

MARS OUTPOST

- Oxygen (and perhaps Methane) production from the Carbon Dioxide Atmosphere
- Water production from the atmosphere or soil

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Technology Program

Major Elements of the Technology Program:

- Systems Concepts
- Basic Resource Processing Methods
- Process Engineering
- Planetary Mining
- Raw Materials Preparation
- Validation, Testbeds, and Flight Experiments

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NASA

In Space Resource Utilization (ISRU)

STATE-OF-THE-ART ASSESSMENT

- LUNAR SAMPLES WELL STUDIED
  - COMPOSITION WELL CHARACTERIZED FOR SIX APOLLO SITES
  - COMPOSITION KNOWN TO VARY OVER SURFACE (MOSTLY IN METAL SPECIES)
- CHEMISTRY OF MANY LUNAR REGOLITH PRODUCTION PROCESSES DEFINED, BUT ONLY A FEW STUDIES IN THE LABORATORY
  - MOST EMPHASIS HAS BEEN PLACED ON OXYGEN PRODUCTION
  - OTHER MATERIALS (METALS, GASSES) CONSIDERED AS BY-PRODUCTS
- VERY LITTLE PROCESS ENGINEERING
  - HYDROGEN REDUCTION OF ILMENITE MOST HIGHLY DEVELOPED PROCESS
  - HOT ELECTROLYSIS CONCEPTS DEVELOPED BUT TECHNICAL VIABILITY NOT ESTABLISHED
  - SOME COMMERCIAL TECHNOLOGIES MAY BE MODIFIED FOR OXYGEN PRODUCTION

NASA

In Space Resource Utilization (ISRU)

STATE-OF-THE-ART ASSESSMENT

- MINING TECHNOLOGY HAS ONLY BEEN STUDIED ON PAPER
- EXTRACTION OF OXYGEN FROM THE MARTIAN ATMOSPHERE DEMONSTRATED ON A SMALL-SCALE, TECHNOLOGY NOT DEVELOPED
- LIFE SUPPORT CHEMISTRY OF CO_2 TO O_2 AND CH_4 WELL EXPLORED
- *OVERALL RISK CONSIDERED MODERATE - PROCESSING METHODOLOGY AND RAW MATERIALS ARE SIMILAR TO EXPERIENCE ON EARTH BUT EXTRATERRESTRIAL PRODUCTION IS MUCH MORE CHALLENGING*

NASA

Technology Program

Overall Task Schedule /Milestones:

- Select 4-6 candidate lunar processes for oxygen production and 2 candidate processes for metals and ceramics - FY 1993
- Select 2-3 processes for development of advanced chemical fundamentals - FY 1994
- Design benchtop pilot plants for two oxygen production processes - FY 1995
- Validate at least one process each for production of oxygen, construction materials (metals and ceramics), and volatiles FY1996
- Complete design of small-scale flight experiment to test critical process parameters on the lunar surface - FY 1997
- Validate breadboard pilot plant(s) operation for at least one processes to produce oxygen, ceramics, metals and volatiles - FY 1998

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Technology Program

Overall Task Schedule /Milestones:

- Initial breadboard demonstration of excavation and beneficiation for at least two processes - FY 1998
- Begin operation of laboratory testbed pilot plant(s) for processes to produce oxygen, ceramics, metals and volatiles - FY 2000
- Begin operation of laboratory testbed pilot plants for mining and beneficiation - FY 2001
- Validate end-to-end production capability of one plant concept, including basic process automation - FY 2001
- Validate long-term durability of plant concept to enable confident design of a large-scale production plant - FY 2002

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Systems Concepts

Task Schedule/Milestones:

- Identification of oxygen processing options and volatile extraction options and development of database with existing data -FY 1993
- Selection of 4-6 candidate lunar processes for oxygen production and 2 candidate processes for metals and ceramics- Fy 1994
- Select 2-3 processes for development of advanced chemical fundamentals - FY1994
- Identification of options for mining/solid transport/beneficiation; database development - FY1995
- Subsystems analysis for most promising candidate processes to identify key areas for focussed effort FY-1995

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Basic Resource Processing Methods

Task Schedule/Milestones:

- Identify and design laboratory apparatus necessary for chemical experiments and begin fabrication -FY 1993
- Finish fabrication of experimental apparatus and begin basic testing on a number of processes Fy 1994
- Select 2-3 processes for development of advanced chemical fundamentals - FY1994
- Begin advanced chemical fundamentals for candidate processes and feed data to database and computer modeling - FY1995
- Produce ceramic and metal products and begin property testing- FY1995

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Systems Concepts

Task Schedule/Milestones:

- Computer modeling of oxygen processes based on new chemical fundamentals - FY1996
- Systems design and computer modeling of mining/solid transport/beneficiation systems-FY1996
- Computer modeling of metals, ceramics, volatiles using integrated plant concepts - FY1997
- Addition of mining/solid transport/beneficiation to integrated plant concepts/computer models -FY1998
- Addition of automation and reliability modeling to provide end-to-end models of 2 integrated systems FY 1999

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Basic Resource Processing Methods

Task Schedule/Milestones:

- Validate oxygen production with reagent recycle from two processes- FY1996
- Validate integrated oxygen/metals production process chemistry and optimize conditions- FY1996
- Determine advanced chemical fundamentals on alternate advanced process concepts - FY1997
- Determine optimized temperature/pressure/feedstock conditions for two most promising oxygen processes FY-1998
- Determine effect on chemical fundamentals of advanced processing concepts such as microwave, ultrasonic, and plasma enhancement - FY1999

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Process Engineering

Task Schedule/Milestones:

- Identify critical components and subsystems and begin initial evaluations - FY1993
- Perform mechanical/tribology testing on critical components - FY1994
- Select critical components from 2-4 oxygen processes and carry out focused mechanical/thermal/tribology experiments - FY 1995
- Complete design and fabrication of laboratory bench-scale subsystems and evaluate mechanical/thermal properties - FY1996
- Final design and fabrication of testbed subsystem hardware using data from previous testing -FY-1997
- Testbed fabrication of integrated systems using validated subsystems - FY1999
- Begin testbed operation and validation testing of integrated system to produce oxygen, ceramics, metals, and volatiles - FY2001

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Planetary Mining

Task Schedule/Milestones:

- Identify potential requirements for mining and ore transport, and propose 2-3 non-conventional systems for further investigation - FY1993
- Survey existing technology in the identified non-conventional areas identified - FY1993
- Design, acquire, and certify suitable simulated lunar materials for mining experiments - FY1993
- Perform engineering analysis on candidate systems and identify key unknowns for experimental investigation - FY 1994
- Design, fabricate, and begin testing of 2-3 laboratory bench-scale mining devices for testing with simulants - FY1995

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Planetary Mining

Task Schedule/Milestones:

- Complete testing and validation of bench-scale units to acquire new engineering design data on performance and operation parameters FY - 1996
- Design and fabrication of testbed mining subsystems hardware (1-2 units) using data from previous testing -FY-1997
- Complete testing of subsystems and design for integration of subsystems into end-to-end testbed FY- 1998
- Begin testbed fabrication of integrated systems using validated subsystems - FY1999
- Begin testbed operation and validation testing of integrated system, to produce oxygen, ceramics, metals, and volatiles - FY2001

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Raw Materials Preparation

Task Schedule/Milestones:

- Identify potential requirements for feedstock beneficiation and sizing for candidate processes - FY1994
- Design, acquire, and certify suitable simulated lunar materials for chemical fundamentals - FY1994
- Evaluate beneficiation and sizing methods and choose 2-3 for detailed investigation - FY 1995
- Design, fabricate, and begin testing of 2-3 beneficiation and sizing devices for testing with simulants - FY1995

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Raw Materials Preparation

Task Schedule/Milestones:

- Complete testing and validation of bench-scale units to acquire new engineering design data on performance and operation parameters FY - 1996
- Design and fabrication of test bed beneficiation/sizing subsystems hardware (1-2 units) using data from previous testing -FY-1997
- Complete testing of subsystems and design for integration of subsystems into end-to-end test ted FY- 1998
- Testbed fabrication of integrated systems using validated subsystems - FY1999
- Begin testbed operation and validation testing of integrated system, to produce oxygen, ceramics, metals, and volatiles - FY2001

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Validation, Testbeds, and Flight Experiments

Task Schedule/Milestones:

- Identification of potential testbed systems and potential flight experiments - FY 1993
- Preliminary testbed concepts/design for the oxygen, volatile extraction, ceramic, and metal processes identified in other subelements- Fy 1994
- Select 2-3 processes for testbed design - FY1994
- Select 2-3 processes for flight experiment concept development - FY1995
- Complete detailed design of small-scale flight experiment to test critical process parameters on the lunar surface FY - 1997

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Validation, Testbeds, and Flight Experiments

Task Schedule/Milestones:

- Produce preliminary design for small-scale martian propellant production flight experiment using Mars atmosphere for feedstock - FY1997
- Begin construction/fabrication of testbeds for processing validation using 1-2 designs -FY1997
- Begin validation testing using testbeds - FY2000
- Validate end-to-end production capability of one plant concept, including basic process automation - FY2001

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Utilization of Lunar and Mars Resources

- What are these resources?
- Why are they useful?
- What is our overall strategy?
- What is our technology plan?
- What are we doing now? ←
- What else is going on related to resource utilization?
- What happens next?

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Utilization of Lunar and Mars Resources

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- Why are they useful?
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- What are we doing now?
- What else is going on related to resource utilization?
- What happens next? ←

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Some Current Activities

- Johnson Space Center
  - Production of oxygen from glasses using CO and H2
  - Production of oxygen from sulfuric acid solution electrolysis (dissolved ilmenite)
  - Sintering and melting of lunar simulants to make bricks
  - A variety of studies of lunar samples
  - Engineering systems studies for sulfate process
  - Engineering systems studies for lunar volatile production and methane production
  - Reduced gravity testing of pneumatic systems

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Some Current Activities

- Current Small Business Innovative Research Contracts
  - EMEC Company: Fused melt electrolysis (Rudi Keller)
  - Physical Sciences Inc: Regolith pyrolysis (Connie Acton)
  - Foster Miller Co.: Plasma disassociation (Harris Cole)
- Other activities
  - Reduced gravity system testing by aircraft (Carbotek)
  - SERC at University of Arizona (Terry Triffet)
  - Various university grants and programs
  - Corporate IR&D

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Utilization of Lunar and Mars Resources

- What are these resources?
- **Why are they useful?**
- **What is our overall strategy?**
- **What is our technology plan?**
- **What are we doing now?**
- What else is going on related to resource utilization?
- **What happens next?**

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Technology Program

OTHER DEVELOPMENT EFFORTS

- UNIVERSITY SPACE ENGINEERING RESEARCH CENTER AT THE UNIVERSITY OF ARIZONA: CENTER FOR THE UTILIZATION OF LOCAL PLANETARY RESOURCES
  - MAJOR INTEREST PROPELLANT PRODUCTION
  - DEVELOPING SMALL MARTIAN ATMOSPHERE REDUCTION PLANT TO PRODUCE OXYGEN
  - SOME PIONEERING WORK IN INNOVATIVE PROCESSING OF LUNAR REGOLITH
- A FEW SMALL EFFORTS: SBIR AND UNIVERSITY GRANTS, MOSTLY O2
- SIGNIFICANT INTEREST DUE TO LARGE FUNDING POTENTIAL BY MAJOR INDUSTRIES BUT VERY LITTLE CURRENT FUNDING
- INTEREST BY BUREAU OF MINES IN EXTRATERRESTRIAL MINING
- INTEREST BY DOE IN ISRU BUT LIMITED EXPERTISE

ISRU WAS VERY ACTIVE IN THE 1960'S AND EARLY 1970'S WHEN EXTENSIVE EXPLORATION WAS ANTICIPATED BUT RELATIVELY LITTLE NEW DEVELOPMENT SINCE THEN

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Related Activities

- Analysis of Synthesis Report architectures and identification of ISRU requirements
- Strawman site selection workshops to design process
- Identification of precursor robotic mission requirements
- Compilation of "design-to" data bases on lunar and Mars areas or specific sites
- Continuing analysis of lunar samples, including engineering-related studies
- Continuing remote sensing telescopic studies of moon and Mars
- Initial design, production, and analysis of simulants for lunar and Mars materials

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Utilization of Lunar and Mars Resources

- What are these resources?
- Why are they useful?
- What is our overall strategy?
- What is our technology plan?
- What are we doing now?
- What else is going on related to resource utilization?
- What happens next? ←

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In Space Resource Utilization (ISRU)

Technology Challenges

- Develop robust, economical production methods
  - Long term durability--over 10 years with minimum maintenance
  - Reliable operation in a harsh environment--vacuum, cold, dust
  - Low maintenance-- ease of shutdown, inspection, repair, modular
    - LOW WEIGHT - TO REDUCE LAUNCH COSTS
    - HIGH YIELD PER TON OF MINED MATERIAL
    - AUTONOMOUS; LOW ASTRONAUT REQUIREMENTS
    - GEOCHEMICAL INVESTIGATION TO CONFIRM PROCESS SUITABILITY
  - RECOVERY AND RECYCLE OF CONSUMED PROCESSING MATERIALS (REAGENTS ELECTRODE MATERIAL, ETC.) TO MINIMIZE EARTH-SUPPLIED MATERIALS

TECHNICAL APPROACH

- VALIDATE PROCESS CHEMISTRY FOR MULTIPLE PROCESSES
- DEVELOP DETAILED CHEMISTRY AND PROCESS ENGINEERING FOR A FEW PROCESSES
- DEVELOP LABORATORY PILOT PLANTS FOR SELECTED PROCESSES
- VALIDATE METHODOLOGY BY SMALL-SCALE PLANTS ON LUNAR/MARTIAN SURFACE
- INCREASE SCALE TO PRODUCTION PLANT LEVEL
- USE LUNAR EXPERIENCE TO GUIDE DEVELOPMENT OF SYSTEMS FOR MARS

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MILESTONES

- Select 4-6 candidate lunar processes for oxygen production and 2 candidate processes for metals and ceramics - FY 1993
- Select 2-3 processes for development of advanced chemical fundamentals - FY 1994
- Design benchtop pilot plants for two oxygen production processes - FY 1995
- Validate at least one process each for production of oxygen, construction materials (metals and ceramics) and volatiles - FY 1996
- *Complete design of small-scale flight experiments to test process methods and critical parameters for oxygen, construction materials and volatiles production on the lunar surface - FY 1997 SUPPORTS INITIAL LUNAR OUTPOST*
- Validate breadboard pilot plant(s) operation for at least one process to produce oxygen, ceramics, metals and volatiles -FY1997
- Initial breadboard demonstration of excavation and beneficiation for at least two processes - FY 1998
- Begin operation of laboratory testbed pilot plant(s) for processes to produce oxygen, ceramics, metals and volatiles - FY 2000
- Begin operation of laboratory testbed pilot plants for mining and beneficiation - FY 2001
- Validate end-to-end production capability of one plant concept, including basic process automation - FY 2001
- *Validate long-term durability of plant concept to enable confident design of a moderate scale production plant - FY 2002 SUPPORTS BEGINNING OF SELF-SUFFICIENCY*

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MISSION READINESS SCHEDULE

By 1996-1997:

Validated chemical extraction processes to produce oxygen and co-products from lunar regolith

Validated production processes (1-2) with laboratory testbed hardware:

a) Mining system
b) Beneficiation system
c) Production plant

Design concept for a ground-based experimental production pilot plant to validate large-scale production methods

Design concept for a lunar-based experimental production pilot plant to validate large-scale production methods

By 2001-2003 (mission dependent)

End-to-end production plant design for oxygen (and co-products) validated by laboratory pilot plant hardware (1-2) demonstrating:

a) Component and system durability
b) Overall process automation
c) Efficient start-up, shut-down and slow-down
d) Ease of maintenance

By 2010 (approximately)

Production methods and plant concepts for Martian water, methane, and oxygen production

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ISRU Budget Guideline

	FY93	FY94	FY95	FY96	FY97	FY98	FY99
APRIL 91 GUIDELINE ($M)	3.0	5.0	8.0	12.0	13.0	14.0	15.0
JUNE 91 GUIDELINE ($M)	1.5	3.0	6.2	6.7	8.0	?	?

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Technology Priorities

Budget levels will dictate how far down the priority list we will go.
Current priorities:

I. Initial emphasis to support early lunar outpost

1. Evaluation of basic process chemistry
   - Oxygen
   - Construction materials
   - Volatiles
   - Metal byproducts

2. Critical process engineering

3. Development of early lunar experiment (robotic or man-tended)

4. Pilot plant development (earth test bed)

5. Mining

II. Mars Outpost

III. Lunar Self-sufficiency (manufacturing and fabrication)

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Summary

1. The technology development program will be driven by needs.
   - Basic purpose is to save costs to the SEI program.
   - Secondary purpose is to push state-of-art in chemical processing, automation, recycling wastes, increasing reliability of processing, and discovering innovative methods and technologies.
   - Breakthroughs may influence mission designs and architectures.
2. ISRU has a potentially high payoff.
   - 90-day report suggested savings of $30 billion dollars and identified ISRU as on of 7 critical technologies.
   - Stafford Synthesis Study Report identified ISRU as one of 14 critical technologies.
3. While no NASA program exists, much has been done using SBIR funds, CDDF funds, and misc. fund sources.
   - We know that a few processes look promising, feasible, and probably economic.
   - We know what to work on next.

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Summary (continued)

4. Even without significant funding, we have a good program in place and some good people working on it--we have done our homework.

5. We believe that this technology is absolutely vital to a viable SEI program and will also help capture public support by demonstrating practical results that people can identify with.

6. ISRU technology development has been signaled out as a major goal in Japan by industry such as Shimizu and Obayashi Corporations as well as by NASDA. The U.S. program cannot afford to neglect this topic any longer.

7. We can do much with a modest amount of money and can leverage it with SBIR funds and IRAD funds. The private sector is very interested but requires some sign of commitment by NASA.

8. We need to start now to have the required technology developed for a series of decision points as SEI takes form.

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Postscript

- The Stafford Synthesis Committee refers to utilization of space resources many many times throughout its report and identifies it as one of the critical technologies which must be developed .
- One of the four Architectures is called *Space Resource Utilization* and is primarily focussed on extracting and using the resources of the moon.
- Yet we have no formal NASA program to develop this technology
- We must start such a program and give it a priority commensurate with that given by the Stafford committee.

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P. 6

INTEGRATED TECHNOLOGY PLAN
FOR THE CIVIL SPACE PROGRAM

EXPLORATION TECHNOLOGY
SURFACE SYSTEMS

SURFACE HABITATS AND CONSTRUCTION (SHAC)

MURRAY HIRSCHBEIN

JUNE 27, 1991

OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON, DC 20546

EXPLORATION TECHNOLOGY PROGRAM - SURFACE SYSTEMS

Objective:

Develop technology emplace and build a outpost on the moon and Mars

Develop concepts for permanent habitats and enclosures on the moon and Mars

Schedule

Candidate concepts for permanent habitats - FY 1994

Methods for passive thermal and duct control - FY 1996

Tool designs for moving and digging regolith - FY 1996

Methods to emplace an initial lunar outpost - radiation protection - FY 1997

Concept for permanant lunar habitat - FY 2000

Breadboard construction of permanent lunar outpost - FY 2002

SURFACE HABITATS AND CONSTRUCTION

Funding ($M):*

FY 1993	*2.0*
FY 1994	*4.0*
FY 1995	*7.0*
FY 1996	*8.0*
FY 1997	*12.0*
FY 1998	*14.0*
FY 1999	*14.7*

"Strategic Plan", - new start not currently scheduled in "3x" plan

Participating Centers:

Johnson Space Center (Lead)

Langley Research Center

SURFACE HABITATS AND CONSTRUCTION (SHAC)

PROGRAM OBJECTIVES

Develop structural concepts and construction operations methodology to enable initial emplacement of an outpost on the moon and Mars and evolution into permanent outposts:

- Methods for site and surface preparation
- Concepts for permanent habitats and enclosures
- Hardware concepts and methods for construction
- Minimize required human resources and earth supplied materials

SURFACE HABITATS AND CONSTRUCTION (SHAC)

WORK BREAKDOWN STRUCTURE

Habitat & Enclosure Concepts

Environment & Dust Control

Site and Surface Preparation

Construction Equipment Concepts

Construction Operations Methods

Validation & Technology Development Testbeds

SURFACE HABITATS AND CONSTRUCTION (SHAC)

TECHNICAL PROGRAM

The Surface Habitats and Construction element of the ETP program will be implemented along six primary thrusts:

1) Materials, structures and design concepts for habitats, workspaces, enclosures, airlocks etc., including the use of in-situ materials
2) Dust control measures and design concept for passive thermal radiators to support habitat environmental control
3) Methods and hardware concepts to prepare a outpost site, and to clear and modify the surface for roads, landing pads, etc.
4) Methods and hardware concepts for general surface construction, including covering "buildings" with regolith
5) Construction operations, including telerobotic methods, to minimize human resources and construction time and assure structural integrity
6) Development of terrestrial laboratory testbeds and breadboards to validate technology

SURFACE HABITATS AND CONSTRUCTION (SHAC)

- PRIMARY CONSIDERATION HAS BEEN TO BUILD HABITATS
  - PRIMARY STRUCTURE

    ERECTABLE
    DEPLOYABLE
    INFLATABLE

  - RADIATION PROTECTION: ***MAJOR ISSUE FOR INITIAL EMPLACEMENT***

    PROTECTIVE COVERING
    NATURAL FEATURES (E.G. LAVA TUBES, CRATER WALLS)
    INHERENT AND PARASITIC (SHIELDING) STRUCTURE

- STATE-OF-THE-ART
  - SPACE STATION FREEDOM HABITAT MODULE DESIGNS
  - INFLATABLE STRUCTURES STUDIED IN THE EARLY 1970'S

    DURABLE MATERIALS
    BOND OR STICHLINE INTEGRITY
    INFLATION DYNAMIC AND END SHAPE

  - 1 - 3 METERS REGOLITH RADIATION PROTECTION

    0.5 - 1.0 LB/SQ. IN LOADING (DENSITY DEPENDENT)
    SHIELDING PROPERTIES NOT WELL MEASURED

SURFACE HABITAT RADIATION SHIELDING

LUNAR HABITAT PROTECTED BY REGOLITH

1-3 METERS OF REGOLITH PROBABLY ADEQUATE FOR LUNAR HABITAT
(SOME ESTIMATES AS HIGH AS 5 METERS DUE TO SHIELDING UNCERTAINTY)

REDUCES RADIATION DOSE INSIDE HABITAT TO NEAR ZERO - TOTAL DOSE WILL BE DUE TO EVA

REGOLITH WEIGHT APPROX. .15 kg/ sq cm to .45 kg/sq cm (1/3 lb/sq in - 1 lb/sq in)

MINIMAL IMPACT ON STRESSES IN HABITAT - DRIVEN BY INTERNAL PRESSURE (ABOUT 10 PSI - 14.7 PSI) FOR BOTH RIGID SHELL AND INFLATABLE CONSTRUCTION

TO COVER A SSF HABITAT MODULE: APPROX. 300 cu m (450 MT)/meter
(A 2-MT, 2-kw "MINER" CAN MOVE REGOLITH AT ABOUT 10-MT/hr)

ON MARS ATMOSPHERE WILL REDUCE GCR DOSE BY ABOUT A FACTOR OF TWO

MATERIALS AND STRUCTURES FOR A LUNAR OUTPOST

SOIL CONSTRUCTION CHARACTERISTICS

- TOP 5-10 INCHES LOOSE REGOLITH
  - VERY FINE ALMOST SILT LIKE
  - ELECTROSTATICALLY CHARGED
  - VERY ABRASIVE
- NEXT FEW METERS HIGHLY COMPACTED
  - 85-90% MAXIMUM DENSITY (TERRERSTRIAL ROAD BED ABOUT 75%)
  - COMPACTION DUE TO MICROMETEROITE IMPACT
  - COHESION MECHANICAL OR ELECTROSTATIC (NO WATER AS ON EARTH)
  - EXCAVATION MAY BE DIFFICULT
- OVERBURDEN SUPPPORT (TUNNELS) - LESS SUPPORT THAN ON EARTH
- ANGLE OF REPOSE (RESISTANCE TO SLIDING) - GREATER THAN ON EARTH
- COMPLEX CONSTITUTIVE BEHAVIOR UNLIKE EARTHEN GRANULAR MATERIALS
- GENERAL HIGH ABRASIVE SILTLIKE CHARACTER POTENTIALLY VERY DAMAGING TO EXPOSED MECHANICAL SYSTEMS

MATERIALS AND STRUCTURES FOR A LUNAR OUTPOST

- IN-SITU MATERIALS

CAST BASALT (VOLCANIC ROCK)

- UNPROCESSED LUNAR REGOLITH FEEDSTOCK
- UP TO 10-TIMES STRONGER THAN CONCRETE
- COMPLEX SHAPES EASILY FORMED AT ABOUT 1000 C
- SENSITIVE TO COOLING RATE
- COMPARABLE COMMERCIAL PROCESS IN FRANCE FOR DUCTS AND PIPES

LUNAR CEMENT

- SILICATES AVAILABLE
- NATURAL AGGREGATES FOR CONCRETE
- ABOUT 90% STRENGTH OF TERRESTRIAL CEMENT
- LOW WATER FORMULATIONS DEVELOPED
- WATER AVAILABLE FROM LUNAR H2 AND O2 (OXYGEN PRODUCTION)
- SENSITIVE TO VACUUM CURE

METALS

- NATURAL BY PRODUCTS OF OXYGEN PRODUCTION
- IRON MOST COMMONLY PRODUCED
- MAGNESIUM, ALUMINUM, TITANIUM AND SILICON READILY AVAILABLE

"FIBER GLASS" PRODUCED BY HEATING AND COMPRESSING SOIL MATERIALS

SURFACE HABITATS AND CONSTRUCTION (SHAC)

CURRENT PROGRAM

- SMALL STUDY PROGRAM (APPROX. $150K) AT JSC

RELATED PROGRAMS

- $100 K/YR GRANT AT COLORADO STATE UNIVERSITY TO DEVELOP AN INFLATABLE CONCEPT
- A MAJOR FOCUS OF UNIVERSITY ENGINEERING CENTER FOR SPACE CONSTRUCTION AT THE UNIVERSITY OF COLORADO
  - SOIL MECHANICS AND PROPERTIES
  - SURFACE HABITAT CONSTRUCTION

    ROBOTIC CONSTRUCTION
    CONSTRUCTION EQUIPMENT CONCEPTS (E.G. "CRANE")
- APPLICABLE ROVER/ROBOTIC CONCEPTS AT CARNEGIE MELLON UNIVERSITY
- LOW LEVEL STUDIES BY BUREAU OF MINES

PRIORITIES - SHAC

DOES NOT PARALLEL TECHNOLOGY DEVELOPMENT SCHEDULE

I INITIAL EMPHASIS TO SUPPORT LUNAR OUTPOST

1) INITIAL HABITAT EMPLACEMENT - RADAITION PROTECTION
2) PASSIVE THERMAL AND DUST CONTROL

II PERMANENT LUNAR HABITAT

1) HABITAT CONCEPTS - EXTERIOR CONSTRUCTION
2) PASSIVE THERMAL AND DUST CONTROL
3) HABITAT CONCEPTS - INTERIOR CONSTRUCTION

III SURFACE EQUIPMENT

1) SURFACE PREPARATION
2) GENERAL CONSTRUCTION

IV MARS OURTPOST

V USE OF IN-SITU MATERIALS

INTEGRATED TECHNOLOGY PLAN
FOR THE CIVIL SPACE PROGRAM

EXPLORATION TECHNOLOGY
SURFACE SYSTEMS

ARTIFICIAL GRAVITY

MURRAY HIRSCHBEIN

JUNE 27, 1991

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ARTIFICIAL GRAVITY

MISSION CRITICAL ISSUE:

CAN ASTRONAUTS SURVIVE SEVERAL MONTHS IN WEIGHTLESSNESS WITHOUT PROLONGED TEMPORARY PHYSICAL DETERIOATION THAT WOULD ENDANGER THE SUCCESS OF A MISSION OR ANY SERIOUS PERMANENT PHYSICAL DAMAGE THAT WOULD ENDANGER THEIR HEALTH?

- A MISSION TO MARS WILL LIKELY TAKE AT LEAST 6 MONTH IN TRANSIT - MORE LIKELY 9 MONTHS
- AN ABORTED MISSION MAY BE THREE YEARS IN LENGTH
- THERE IS NO EXPERIENCE TO *ASSURE* THAT HUMANS CAN SURVIVE LONG PERIODS OF WEIGHTLESSNESS WITHOUT PHYSICAL IMPAREMENT OR DAMAGE IN LESS THAN A 1-G FIELD
- OPTIONS TO PREVENT HEALTH HAZARDS
  - REDUCE MISSION TRANSIT TIME: NUCLEAR PROPULSION
  - MEDICAL COUNTERMEASURES: EXERCISE, MEDICATION
  - PROVIDE ARTIFICIAL GRAVITY: ROTATING SPACECRAFT

ARTIFICIAL GRAVITY

OAET — MATERIALS & STRUCTURES

TECHNICAL ISSUES

- CONTINUOUS CENTRIFIGAL ACCELERATIO)N AT LEVELS BETWEEN .38 G (MARS GRAVITY) AND 1.0 G (EARTH GRAVITY)
  - TRANSIT IN 1.0 G
  - ADAPT TO MARS GRAVITY BEFORE DESCENT TO SURFACE
  - AVOID DISORIENTING CORIOLIS ACCELERATION DURING TRANSIT (CORIOLIS < .2 CENTRIFUGAL, APPROXIMATELY)
  - SPIN RATES AS LOW AS 2 RPM, SPIN RADIUS UP TO 220 M
- DYNAMICS AND CONTROL DURING SPIN-UP, SPIN-DOWN AND ATTITUDE/NAVIGATION CORRECTION - POSSIBLE SERIOUS CONTROL-STRUCTURE INTERACTION PROBLEM
- MUCH OF THE USEFUL SPACECRAFT SHIELDING MASS WILL BE REMOVED FROM THE CREW COMPARTMENT
  - MAY BE MORE COMPATIBLE WITH NUCLEAR THERMAL PROPULSION VEHICLE WHICH REQUIRES SEPARATION AND IS NOT CONTINUOUS THRUST
- *REALISTIC REQUIEMENTS AND CONCEPTS FOR AN ARTIFICIAL VEHICLE NOT YET DEVELOPED - <u>MAY NOT BE A TECHNOLOGY ISSUE</u>*

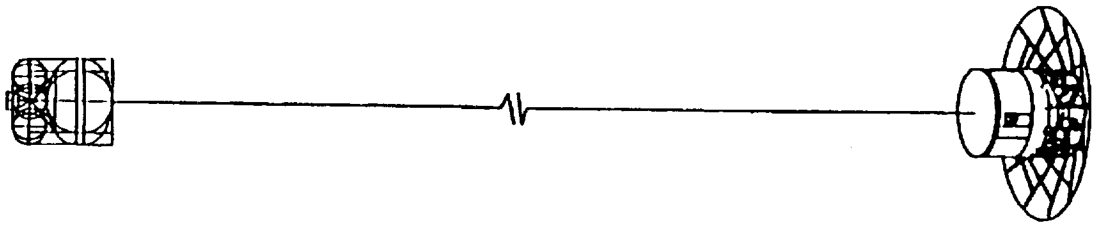
ARTIFICIAL GRAVITY

OAET — MATERIALS & STRUCTURES

- CURRENT PROGRAM: NONE
- STATE OF THE ART
  - HUMAN HEALTH STUDIES (E.G. BED REST, MEDICATION)
  - SOVIET EXPERIENCE
  - LONG-TERM EFFECTS AND COUNTERMEASURES UNCLEAR
- FUTURE PROGRAM STRUCTURE
  - CONCEPT DEVELOPMENT
    DEPLOYMENT/RETRACTION
    TETHERS VS BEAMS
  - DYNAMIC MODELING
  - CONRTOL METHODOLOGY (CSI)
    TWO BODY ("DUMBELL" ARCHITECTURE)
    THREE BODY (CENTER BODY PLUS TWO "OUT RIGGERS")
  - LABORATORY SCALE MODELS

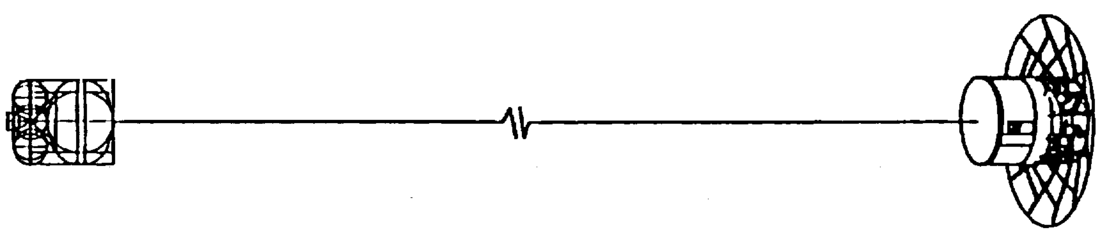
FUNDING ($M)	FY91	FY92	FY93	FY94	FY95	FY96	FY97
"STATEGIC PLAN"	0.0	0.0	0.0	0.0	1.3	1.4	3.6
"3X" PLAN	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Mars Direct Tether Application for Artificial Gravity



- Mars Gravity Achieved with 1500 m Long Tether at Only One RPM
- One RPM also Reduces Wear on Despun Antennas, Solar Panels etc.
- Mission Continues if Tether Fails
- Spent TMIS is Counter-Balance (Residuals Provide Initial Spin-Up)
- No Despin Required: Tether (and TMIS) Simply Released Near Mars
- Total Tether System Mass is 600 kg based on Kevlar and 2 Safety Factor
- Zero-Burning of TMIS *Reduces* Tether System Mass

Mars Direct Tether Application for Artificial Gravity



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- Zero-Burning of TMIS *Reduces* Tether System Mass

OMIT TO
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MATERIALS AND STRUCTURES DIVISION

OAET

INTEGRATED TECHNOLOGY PLAN
FOR THE CIVIL SPACE PROGRAM

IN-SPACE TECHNOLOGY FLIGHT EXPERIMENTS

SAM VENNERI

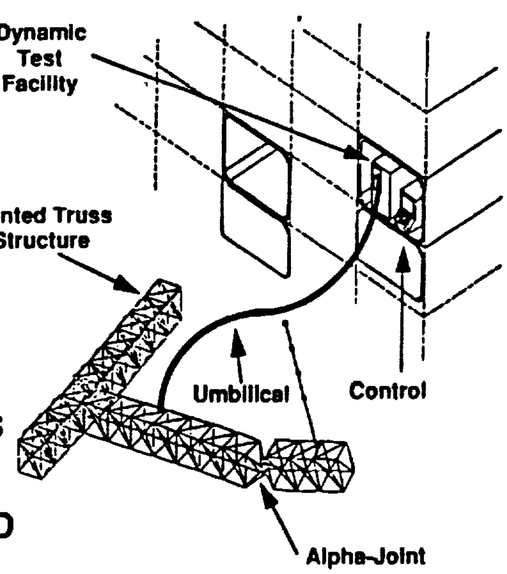
JUNE 27, 1991

OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON, DC 20546

MIDDECK O-GRAVITY DYNAMICS EXPERIMENT (MODE)

MASSACHUSETTS INSTITUTE OF TECHNOLOGY (LaRC)



OBJECTIVE:

- MEASURE EFFECTS OF MICROGRAVITY ON THE DYNAMIC CHARACTERISTICS OF JOINTED-TRUSS STRUCTURES (SUCH AS SPACE STATION ALPHA-JOINT)
- INVESTIGATE THE DYNAMICS OF FLUID-SPACECRAFT INTERACTION IN 0-G

APPROACH:

- DEVELOP A MICROGRAVITY, DYNAMIC TEST FACILITY TO INDUCE KNOWN DISTURBANCES IN TEST ARTICLES, MEASURE DYNAMIC RESPONSES & DETERMINE METHODS OF PREDICTING DYNAMICS OF STRUCTURES AND FLUIDS IN THE 0-G ENVIRONMENT
- EXPERIMENT COST: $1.9M   FLIGHT DATA: 9/91 (STS-48)
  MIDDECK (2 1/2 LOCKERS)

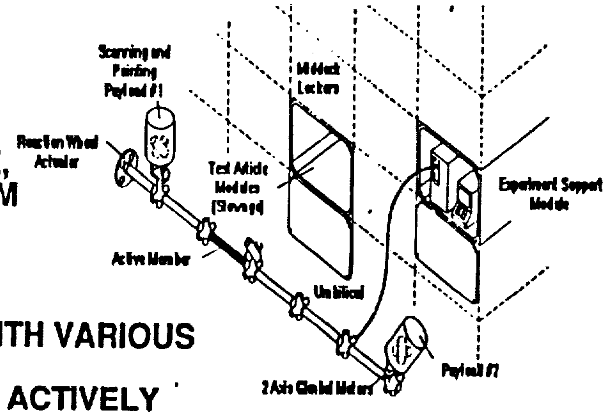
APPLICATION:

- VALIDATED PREDICTION & ANALYTICAL MODELING TECHNIQUES WILL PROVIDE ABILITY TO DESIGN & CONTROL LARGE SPACE STRUCTURES (i.e., SPACE STATION)

35.12N7-2 9/90

MIDDECK ACTIVE CONTROL EXPERIMENT (MACE)

MASSACHUSETTS INSTITUTE OF TECHNOLOGY (LARC)



OBJECTIVE:

- INVESTIGATE THE CONTROL/ STRUCTURES INTERACTION (CSI) OF AN ACTIVELY CONTROLLED, FLEXIBLE, ARTICULATING, MULTIBODY PLATFORM IN MICROGRAVITY

APPROACH:

- EXCITE THE MULTIBODY PLATFORM WITH VARIOUS INPUT DEVICES
- MEASURE DYNAMIC RESPONSE WHILE ACTIVELY CONTROLLING STRUCTURE
- CORRELATE RESULTS WITH ANALYTICAL MODELS & GROUND TEST RESULTS

- EXPERIMENT COST: $7.8M FLIGHT DATA: 6/94, MIDDECK

APPLICATION:

- FLIGHT DATA PROVIDES FUNDAMENTAL UNDERSTANDING OF THE EFFECTS OF MICROGRAVITY ON THE INTERACTION BETWEEN THE DYNAMICS OF THE STRUCTURE AND CONTROL OF STRUCTURE

- ENABLES THE CONTROL OF FUTURE LARGE SPACE STRUCTURES (SUCH AS PRECISION SEGMENTED REFLECTORS)

35.12N.8.11 9/90

DEBRIS COLLISION WARNING SYSTEM (DCWS)

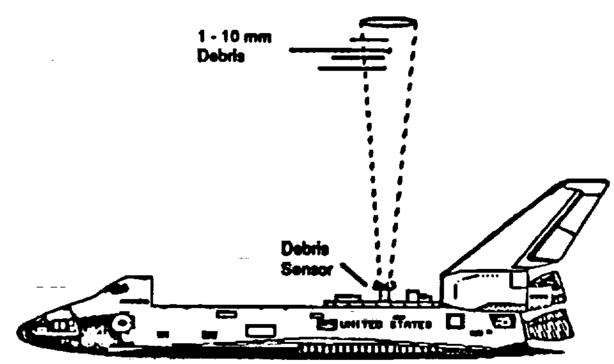
JOHNSON SPACE CENTER

OBJECTIVE:

- QUANTIFY 1-10 MILLIMETER (mm) DEBRIS IN LOW EARTH ORBIT & DETERMINE ALBEDO & SPECTRAL CHARACTERISTICS OF DEBRIS

APPROACH:

- DEVELOP INFRARED & OPTICAL SENSOR TO DETECT SMALL DEBRIS (1-10MM) UNDETECTABLE BY GROUND BASED RADAR & MEASURE DEBRIS REFLECTIVITY
- MEASURE STATISTICAL SAMPLES OF DEBRIS IN LEO TO DETERMINE LOCATIONS OF CONCENTRATIONS



- EXPERIMENT COST - PHASE A ESTIMATE: $35M FLIGHT DATA: 1996/1997 (MPESS OR PALLET)

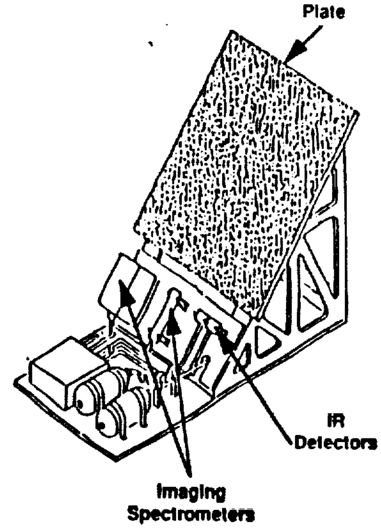
APPLICATION:

- DEBRIS CONCENTRATION LOCATIONS WILL PROVIDE FLIGHT DATA TO CORRELATE WITH CAUSES & UPGRADE LEO DEBRIS MODEL
- VALIDATED SENSOR CAN BE MODIFIED TO USE AS DEBRIS WARNING DEVICE FOR SPACE STATION

35.12N7-5- 9/90

EXPERIMENTAL INVESTIGATION OF SPACECRAFT GLOW (EISG)

LOCKHEED MISSILE AND SPACE COMPANY (JSC)



OBJECTIVE:

- DETERMINE THE MECHANISM CAUSING FORMATION OF GLOW PRODUCING MOLECULES & ASSESS THE EFFECTS OF TEMPERATURE ON GLOW EMISSION

APPROACH:

- MEASURE THE INTENSITY OF ENERGY RELEASED IN THE ULTRAVIOLET, INFRARED & VISIBLE SPECTRUM FROM GLOW PRODUCING MATERIALS SUBJECTED TO ATOMIC OXYGEN PARTICLE ABSORPTION AT VARIOUS TEMPERATURES
- EXPERIMENT COST: $4.2M FLIGHT DATA: 5/93 (STS-62) OAET-1 (HH-M)

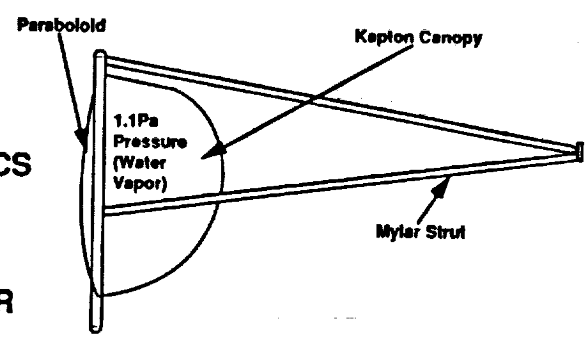
APPLICATION:

- RESULTS WILL ENABLE THE DEVELOPMENT OF NON-GLOWING SURFACE COATINGS FOR REDUCING SPECTRAL INTERFERENCE IN OPTICAL SENSORS

35.12N7-4 9/90

INFLATABLE PARABOLOID

L'GARDE, INC. (JPL)



OBJECTIVE:

- VALIDATE ERECTION OF A PACKAGED 28 METER PARABOLOID
- DETERMINE THE STRUCTURAL DYNAMICS & SURFACE ACCURACY

APPROACH:

- INFLATE STRUCTURE & ANTENNA AFTER INSERTION IN LOW EARTH ORBIT
- MEASURE PARABOLOID ACCURACY AT VARIOUS PRESSURES & SUN ANGLES WITH SURFACE IMAGER
- PERTURB ANTENNA WITH REACTION JETS & GATHER RESPONSE WITH SURFACE IMAGER

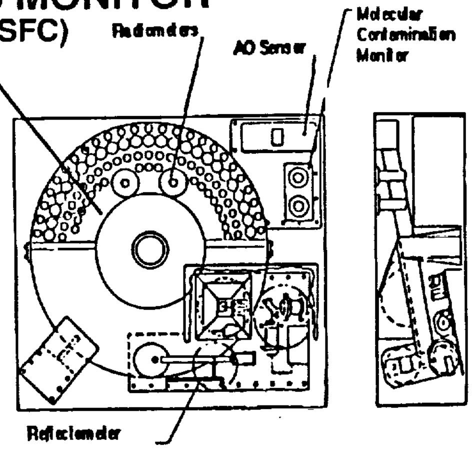
- EXPERIMENT COST: $9.0M FLIGHT DATA: TBD, NSTS OR ELV

APPLICATION:

- ULTRA LIGHTWEIGHT, LOW COST APPROACH FOR LARGE MODERATE ACCURACY REFLECTORS
- POSSIBLE BREAKTHROUGH TECHNOLOGY FOR EXPLORATION INITIATIVE OR EVOLUTIONARY SPACE STATION

35.12N.8.4 9/90

OPTICAL PROPERTIES MONITOR
AZ TECHNOLOGY (MSFC)



OBJECTIVE:

- DETERMINE THE EFFECTS OF THE SPACE ENVIRONMENT ON CRITICAL SPACECRAFT AND OPTICAL MATERIALS

APPROACH:

- SPECTRAL REFLECTANCE, TOTAL INTEGRATED SCATTER AND ULTRA-VIOLET REFLECTANCE/TRANSMITTANCE WILL BE MEASURED IN-SITU AND POST-FLIGHT TO DETERMINE OPTICAL, MECHANICAL, ELECTRICAL AND EROSION EFFECTS
- EXPERIMENT COST: TBD FLIGHT DATA: 10/93, EURECA-2

APPLICATION:

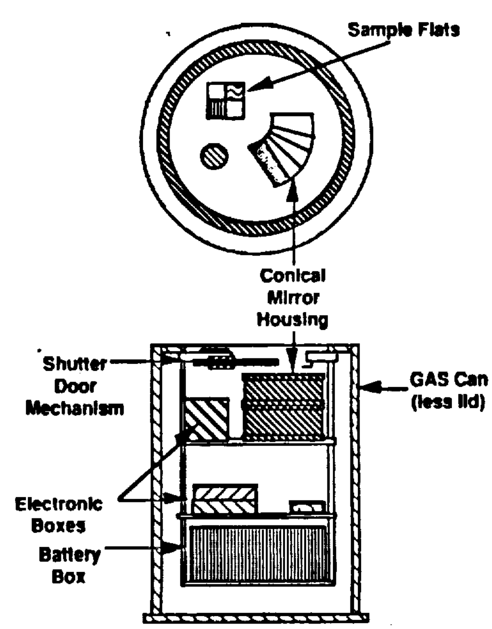
- IMPROVE OPTICAL COATINGS FOR ADVANCED SENSORS AND MATERIALS FOR ADVANCED SPACECRAFT
- UPGRADE ABILITY TO PREDICT DEGRADATION OF MATERIALS & COATINGS DUE TO THE SPACE ENVIRONMENT

35.12N.8.13 9/90

THIN FOIL MIRROR (TFM)
GODDARD SPACE FLIGHT CENTER

OBJECTIVE:

- MEASURE DEGRADATION OF X-RAY REFLECTION EFFICIENCY DUE TO INTERACTION WITH ATOMIC OXYGEN FOR CANDIDATE MIRROR SURFACES
- DETERMINE EFFECTIVENESS OF PROTECTIVE COATINGS TO MINIMIZE SURFACE DEGRADATION



APPROACH:

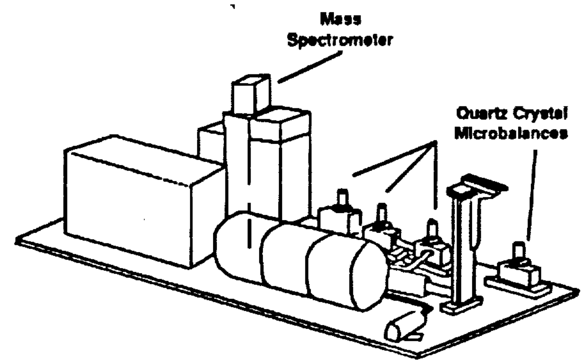
- SERIES OF LACQUER-COATED, HIGH REFLECTIVITY ALUMINUM FOILS WITH 500 ANGSTROM GOLD LAYER AND MIRRORS WITH VARIOUS PROTECTIVE COATINGS SUBJECTED TO INCIDENCE BY ATOMIC OXYGEN PARTICLES
- EXPERIMENT COST: $2.0M
- FLIGHT DATA: 5/93 (STS-62), OAET-1 (CAP)

APPLICATION:

- PROVIDES FLIGHT DATA TO IMPROVE DESIGN AND REDUCE COST OF ADVANCED X-RAY MIRROR SURFACES (i.e., ASTRO-D, SPECTRUM-X, & SPEKTROSAT)

35.12N7-9 9/90

RETURN FLUX EXPERIMENT (REFLEX)
GODDARD SPACE FLIGHT CENTER



OBJECTIVE:

- DETERMINE SPECIE ACCRETION, VELOCITY, DIRECTION & CHEMISTRY OF SPACECRAFT CONTAMINATION

APPROACH:

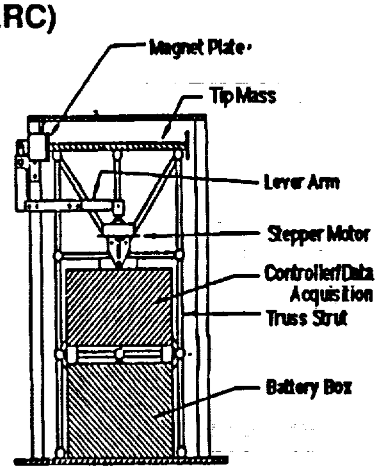
- USE QUARTZ CRYSTAL MICROBALANCES & A MASS SPECTROMETER TO MEASURE MOLECULAR CONSTITUTENTS OF ENVIRONMENT AROUND A SPACECRAFT
- RELEASE KNOWN GAS AND CHARACTERIZE RESULTING CONTAMINATION
- EXPERIMENT COST: $5.1M FLIGHT DATA: 7/94, OAET-FLYER (SPARTAN)

APPLICATION:

- FLIGHT RESULTS WILL BE USED TO IMPROVE CONTAMINATION MODELING TECHNIQUES & PREDICTION CODES (INCREASES EFFECTIVENESS OF OPTICAL SENSORS, THERMAL RADIATORS & SOLAR ARRAYS)

OAET IN-SPACE TECHNOLOGY EXPERIMENTS PROGRAM

MEASUREMENTS & MODELING of JOINT DAMPING in SPACE
UTAH STATE UNIVERSITY (LARC)



OBJECTIVE:

- DETERMINE DAMPING BEHAVIOR OF JOINT DOMINATED TRUSS STRUCTURE IN MICROGRAVITY
- UPGRADE PREDICTION TECHNIQUES TO ELIMINATE GRAVITY EFFECTS ON SPACE STRUCTURES

APPROACH:

- EXCITE TRUSS STRUCTURE IN MICROGRAVITY
- MEASURE DYNAMIC RESPONSE OF STRUCTURE
- CORRELATE RESULTS WITH ANALYTICAL MODELS, GROUND AND KC-135 FLIGHT TEST RESULTS
- EXPERIMENT COST: $1.5M FLIGHT DATA: 2/94, CAP

APPLICATION:

- IMPROVE CAPABILITY OF PREDICTING DYNAMIC BEHAVIOR OF JOINT DOMINATED, TRUSS STRUCTURES IN SPACE (i.e., SPACE STATION)
- IMPROVED ANALYTICAL PREDICTIONS WILL REDUCE WEIGHT OF ADVANCED SPACE STRUCTURES

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INTEGRATED TECHNOLOGY PLAN
FOR THE CIVIL SPACE PROGRAM

IN-SPACE TECHNOLOGY FLIGHT EXPERIMENTS

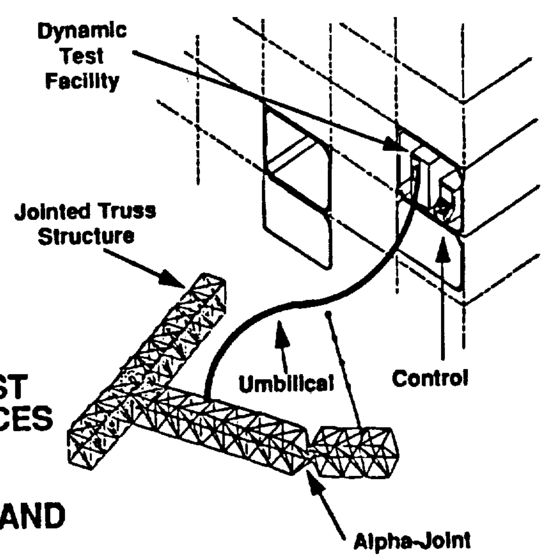
SAM VENNERI

JUNE 27, 1991

OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON, DC 20546

MIDDECK 0-GRAVITY DYNAMICS EXPERIMENT (MODE)
MASSACHUSETTS INSTITUTE OF TECHNOLOGY (LaRC)



OBJECTIVE:

- MEASURE EFFECTS OF MICROGRAVITY ON THE DYNAMIC CHARACTERISTICS OF JOINTED-TRUSS STRUCTURES (SUCH AS SPACE STATION ALPHA-JOINT)
- INVESTIGATE THE DYNAMICS OF FLUID-SPACECRAFT INTERACTION IN 0-G

APPROACH:

- DEVELOP A MICROGRAVITY, DYNAMIC TEST FACILITY TO INDUCE KNOWN DISTURBANCES IN TEST ARTICLES, MEASURE DYNAMIC RESPONSES & DETERMINE METHODS OF PREDICTING DYNAMICS OF STRUCTURES AND FLUIDS IN THE 0-G ENVIRONMENT

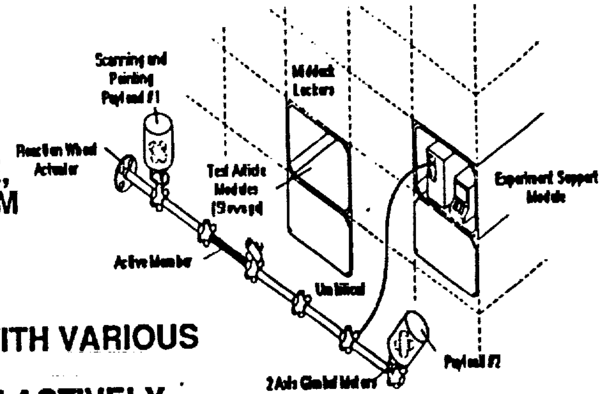
- EXPERIMENT COST: $1.9M   FLIGHT DATA: 9/91 (STS-48)
  MIDDECK (2 1/2 LOCKERS)

APPLICATION:

- VALIDATED PREDICTION & ANALYTICAL MODELING TECHNIQUES WILL PROVIDE ABILITY TO DESIGN & CONTROL LARGE SPACE STRUCTURES (i.e., SPACE STATION)

35.12N7-2 9/90

MIDDECK ACTIVE CONTROL EXPERIMENT (MACE)
MASSACHUSETTS INSTITUTE OF TECHNOLOGY (LARC)



OBJECTIVE:

- INVESTIGATE THE CONTROL/ STRUCTURES INTERACTION (CSI) OF AN ACTIVELY CONTROLLED, FLEXIBLE, ARTICULATING, MULTIBODY PLATFORM IN MICROGRAVITY

APPROACH:

- EXCITE THE MULTIBODY PLATFORM WITH VARIOUS INPUT DEVICES
- MEASURE DYNAMIC RESPONSE WHILE ACTIVELY CONTROLLING STRUCTURE
- CORRELATE RESULTS WITH ANALYTICAL MODELS & GROUND TEST RESULTS
- EXPERIMENT COST: $7.8M FLIGHT DATA: 6/94, MIDDECK

APPLICATION:

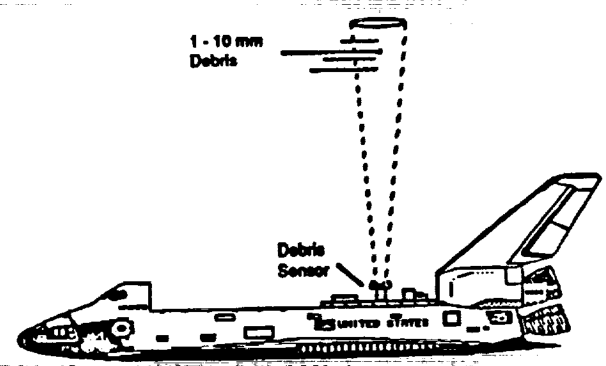
- FLIGHT DATA PROVIDES FUNDAMENTAL UNDERSTANDING OF THE EFFECTS OF MICROGRAVITY ON THE INTERACTION BETWEEN THE DYNAMICS OF THE STRUCTURE AND CONTROL OF STRUCTURE
- ENABLES THE CONTROL OF FUTURE LARGE SPACE STRUCTURES (SUCH AS PRECISION SEGMENTED REFLECTORS)

35.12N.8.11 9/90

DEBRIS COLLISION WARNING SYSTEM (DCWS)
JOHNSON SPACE CENTER

OBJECTIVE:

- QUANTIFY 1-10 MILLIMETER (mm) DEBRIS IN LOW EARTH ORBIT & DETERMINE ALBEDO & SPECTRAL CHARACTERISTICS OF DEBRIS



APPROACH:

- DEVELOP INFRARED & OPTICAL SENSOR TO DETECT SMALL DEBRIS (1-10MM) UNDETECTABLE BY GROUND BASED RADAR & MEASURE DEBRIS REFLECTIVITY
- MEASURE STATISTICAL SAMPLES OF DEBRIS IN LEO TO DETERMINE LOCATIONS OF CONCENTRATIONS
- EXPERIMENT COST - PHASE A ESTIMATE: $35M FLIGHT DATA: 1996/1997 (MPESS OR PALLET)

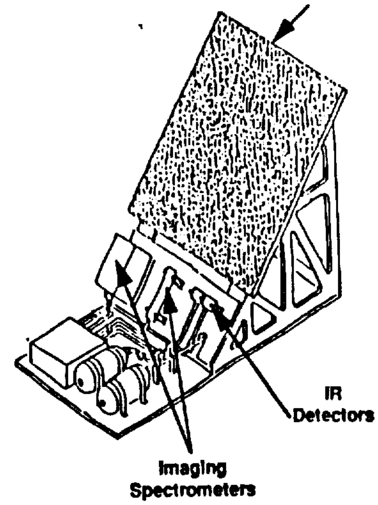
APPLICATION:

- DEBRIS CONCENTRATION LOCATIONS WILL PROVIDE FLIGHT DATA TO CORRELATE WITH CAUSES & UPGRADE LEO DEBRIS MODEL
- VALIDATED SENSOR CAN BE MODIFIED TO USE AS DEBRIS WARNING DEVICE FOR SPACE STATION

35.12N7-5- 9/90

EXPERIMENTAL INVESTIGATION OF SPACECRAFT GLOW (EISG)

LOCKHEED MISSILE AND SPACE COMPANY (JSC)



OBJECTIVE:

- DETERMINE THE MECHANISM CAUSING FORMATION OF GLOW PRODUCING MOLECULES & ASSESS THE EFFECTS OF TEMPERATURE ON GLOW EMISSION

APPROACH:

- MEASURE THE INTENSITY OF ENERGY RELEASED IN THE ULTRAVIOLET, INFRARED & VISIBLE SPECTRUM FROM GLOW PRODUCING MATERIALS SUBJECTED TO ATOMIC OXYGEN PARTICLE ABSORPTION AT VARIOUS TEMPERATURES
- EXPERIMENT COST: $4.2M FLIGHT DATA: 5/93 (STS-62)
  OAET-1 (HH-M)

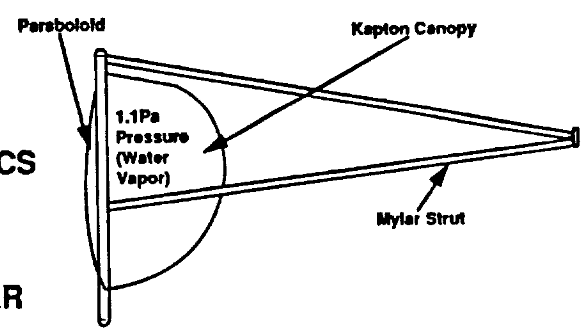
APPLICATION:

- RESULTS WILL ENABLE THE DEVELOPMENT OF NON-GLOWING SURFACE COATINGS FOR REDUCING SPECTRAL INTERFERENCE IN OPTICAL SENSORS

35.12N7-4 9/90

INFLATABLE PARABOLOID

L'GARDE, INC. (JPL)



OBJECTIVE:

- VALIDATE ERECTION OF A PACKAGED 28 METER PARABOLOID
- DETERMINE THE STRUCTURAL DYNAMICS & SURFACE ACCURACY

APPROACH:

- INFLATE STRUCTURE & ANTENNA AFTER INSERTION IN LOW EARTH ORBIT
- MEASURE PARABOLOID ACCURACY AT VARIOUS PRESSURES & SUN ANGLES WITH SURFACE IMAGER
- PERTURB ANTENNA WITH REACTION JETS & GATHER RESPONSE WITH SURFACE IMAGER
- EXPERIMENT COST: $9.0M FLIGHT DATA: TBD, NSTS OR ELV

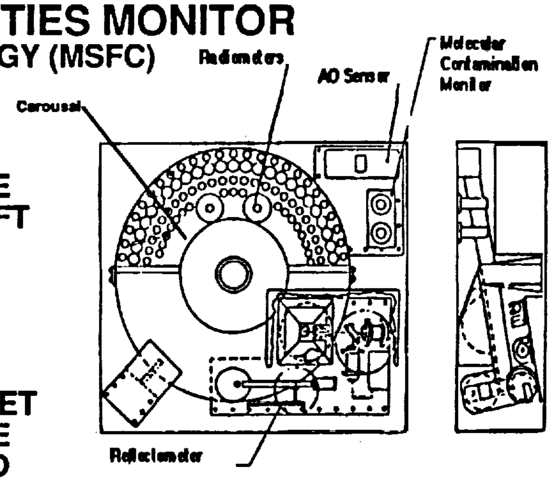
APPLICATION:

- ULTRA LIGHTWEIGHT, LOW COST APPROACH FOR LARGE MODERATE ACCURACY REFLECTORS
- POSSIBLE BREAKTHROUGH TECHNOLOGY FOR EXPLORATION INITIATIVE OR EVOLUTIONARY SPACE STATION

35.12N.8.4 9/90

OPTICAL PROPERTIES MONITOR

AZ TECHNOLOGY (MSFC)



OBJECTIVE:

- DETERMINE THE EFFECTS OF THE SPACE ENVIRONMENT ON CRITICAL SPACECRAFT AND OPTICAL MATERIALS

APPROACH:

- SPECTRAL REFLECTANCE, TOTAL INTEGRATED SCATTER AND ULTRA-VIOLET REFLECTANCE/TRANSMITTANCE WILL BE MEASURED IN-SITU AND POST-FLIGHT TO DETERMINE OPTICAL, MECHANICAL, ELECTRICAL AND EROSION EFFECTS
- EXPERIMENT COST: TBD FLIGHT DATA: 10/93, EURECA-2

APPLICATION:

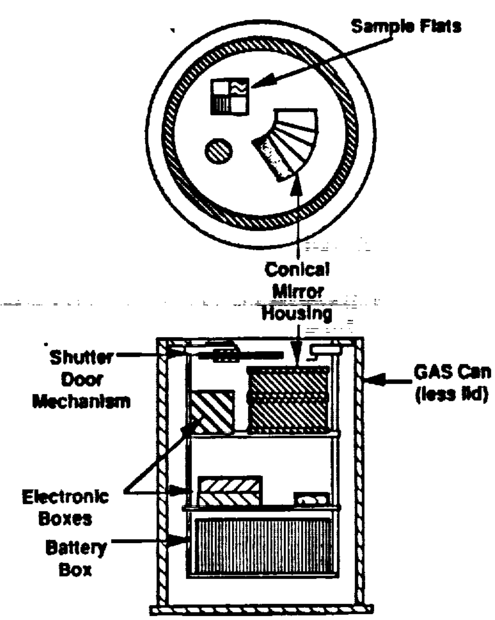
- IMPROVE OPTICAL COATINGS FOR ADVANCED SENSORS AND MATERIALS FOR ADVANCED SPACECRAFT
- UPGRADE ABILITY TO PREDICT DEGRADATION OF MATERIALS & COATINGS DUE TO THE SPACE ENVIRONMENT

THIN FOIL MIRROR (TFM)

GODDARD SPACE FLIGHT CENTER

OBJECTIVE:

- MEASURE DEGRADATION OF X-RAY REFLECTION EFFICIENCY DUE TO INTERACTION WITH ATOMIC OXYGEN FOR CANDIDATE MIRROR SURFACES
- DETERMINE EFFECTIVENESS OF PROTECTIVE COATINGS TO MINIMIZE SURFACE DEGRADATION



APPROACH:

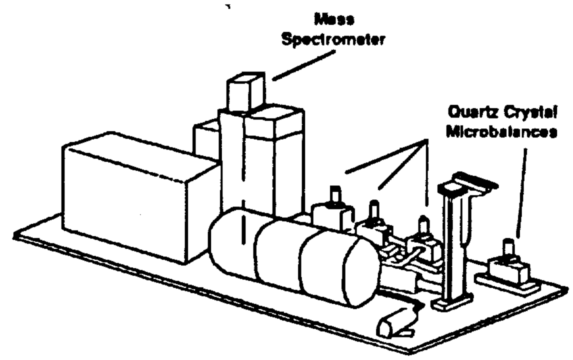
- SERIES OF LACQUER-COATED, HIGH REFLECTIVITY ALUMINUM FOILS WITH 500 ANGSTROM GOLD LAYER AND MIRRORS WITH VARIOUS PROTECTIVE COATINGS SUBJECTED TO INCIDENCE BY ATOMIC OXYGEN PARTICLES
- EXPERIMENT COST: $2.0M
- FLIGHT DATA: 5/93 (STS-62), OAET-1 (CAP)

APPLICATION:

- PROVIDES FLIGHT DATA TO IMPROVE DESIGN AND REDUCE COST OF ADVANCED X-RAY MIRROR SURFACES (i.e., ASTRO-D, SPECTRUM-X, & SPEKTROSAT)

35.12N7-9 9/90

RETURN FLUX EXPERIMENT (REFLEX)
GODDARD SPACE FLIGHT CENTER



OBJECTIVE:

- DETERMINE SPECIE ACCRETION, VELOCITY, DIRECTION & CHEMISTRY OF SPACECRAFT CONTAMINATION

APPROACH:

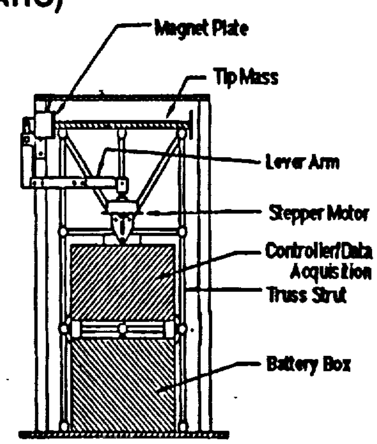
- USE QUARTZ CRYSTAL MICROBALANCES & A MASS SPECTROMETER TO MEASURE MOLECULAR CONSTITUTENTS OF ENVIRONMENT AROUND A SPACECRAFT
- RELEASE KNOWN GAS AND CHARACTERIZE RESULTING CONTAMINATION
- EXPERIMENT COST: $5.1M FLIGHT DATA: 7/94, OAET-FLYER (SPARTAN)

APPLICATION:

- FLIGHT RESULTS WILL BE USED TO IMPROVE CONTAMINATION MODELING TECHNIQUES & PREDICTION CODES (INCREASES EFFECTIVENESS OF OPTICAL SENSORS, THERMAL RADIATORS & SOLAR ARRAYS)

OAET IN-SPACE TECHNOLOGY EXPERIMENTS PROGRAM

MEASUREMENTS & MODELING of JOINT DAMPING in SPACE
UTAH STATE UNIVERSITY (LARC)



OBJECTIVE:

- DETERMINE DAMPING BEHAVIOR OF JOINT DOMINATED TRUSS STRUCTURE IN MICROGRAVITY
- UPGRADE PREDICTION TECHNIQUES TO ELIMINATE GRAVITY EFFECTS ON SPACE STRUCTURES

APPROACH:

- EXCITE TRUSS STRUCTURE IN MICROGRAVITY
- MEASURE DYNAMIC RESPONSE OF STRUCTURE
- CORRELATE RESULTS WITH ANALYTICAL MODELS, GROUND AND KC-135 FLIGHT TEST RESULTS

- EXPERIMENT COST: $1.5M FLIGHT DATA: 2/94, CAP

APPLICATION:

- IMPROVE CAPAB!LITY OF PREDICTING DYNAMIC BEHAVIOR OF JOINT DOMINATED, TRUSS STRUCTURES IN SPACE (i.e., SPACE STATION)
- IMPROVED ANALYTICAL PREDICTIONS WILL REDUCE WEIGHT OF ADVANCED SPACE STRUCTURES

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INTEGRATED TECHNOLOGY PLAN
FOR THE CIVIL SPACE PROGRAM

IN-SPACE TECHNOLOGY FLIGHT EXPERIMENTS

MIDDECK 0-GRAVITY DYNAMICS EXPERIMENT (MODE)

AND

MIDDECK ACTIVE CONTROL EXPERIMENT (MACE)

SAM VENNERI

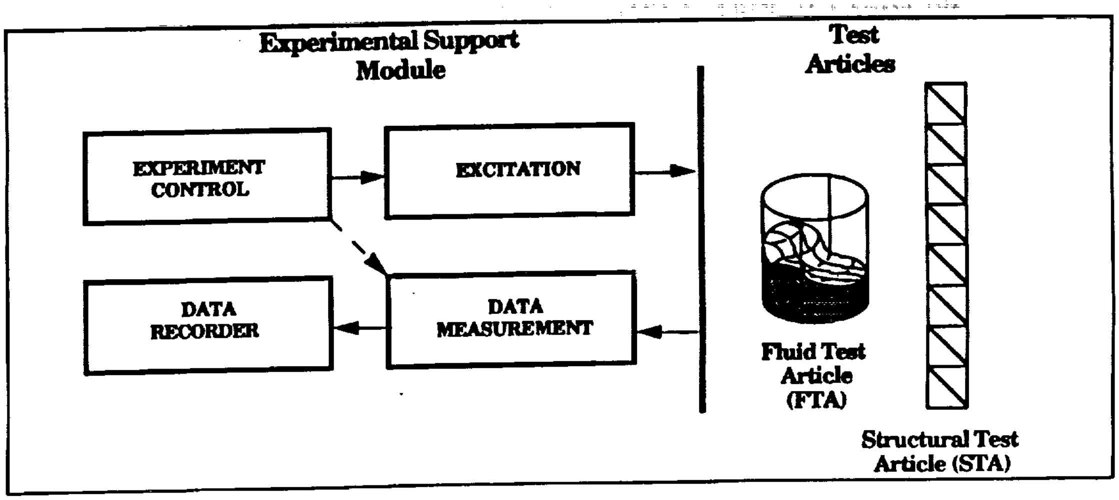
JUNE 27, 1991

OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON, DC 20546

MODE PROGRAM (OVERVIEW)

- In-Step program awarded in 1988.
- Objective is to study gravity dependent nonlinearities associated with fluid slosh and truss structure dynamics.
- MODE provides a reusable facility for on-orbit dynamic testing of small scale test articles in the shirt sleeve environment on the Shuttle middeck.



MODE PROGRAM
(PROGRESS IN PAST YEAR)

- Testbed progress

  Structural test article (STA) designed, procured and delivered,
  STA testing proceeding,
  Design of 6-axis component tester completed,
  Fluid slosh tests are ongoing.

- Flight experiment progress

  Completed Critical Design Review in Spring of 1990,
  90% of flight hardware fabrication completed,
  Phase 2 safety meeting completed.

MODE PROGRAM
(COMPLETION SCHEDULE)

- Flight hardware will be completed in February, 1991.
- Flight assignment at Flight Planning and Storage Review in February, 1991.
- Precursor flight to investigate fluid alignment issues scheduled for SLS 1 in May, 1991.
- Hardware delivery in Aug.-Sept., 1991.
- Tentatively scheduled for STS 48 in Oct.-Nov. 1991 with the UARS payload.

MODE PROGRAM (RESEARCH ACTIVITIES)

- Gravity effects on structural nonlinearity.
- Describing function approach to structural nonlinearity.
- Component force state mapping.
- Modelling of fluid slosh in arbitrary tank geometries and under different gravity loads.

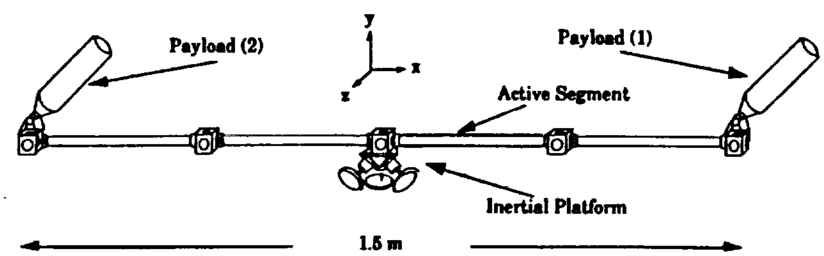
THE MODE FAMILY OF EXPERIMENTS

Fluid Test Article (FTA)	Structural Test Article (STA)	MACE Test Article
Coupled Non-Linear Dynamics of Fluids and Structures in Zero Gravity	Non-Linear Dynamics of Jointed Truss Structures in Zero Gravity	Influence of Gravity on the Active Control of a Multibody Platform
Flight # 1: August 1991		**Flight #2: September 1993**

MACE is part of a logical sequence of cost-effective flight experiments designed to advance technology of interest to NASA in the area of controlled structures.

MULTIBODY TESTBED (OVERVIEW)

- Testbed based on scientific mission for focus of graduate student theses.
- Testbed modelled on a multi-payload platform generically representative of an Earth observing platform.
- Control objectives include single and multiple payload precision pointing and scanning.
- Precision pointing and scanning requirements are on the order of one arc minute RMS which is two orders of magnitude below open-loop response.
- Flight program objective (MACE) is to study gravity effects on the performance and stability of controlled structures.



MULTIBODY PLATFORM (PROGRESS IN PAST YEAR)

- Testbed progress
  - Bus structure, attitude control torque wheel assembly and one two-axis gimbal have been acquired,
  - Three-axis rate gyros, angular encoders, accelerometers, strain gauges and load cells have been acquired,
  - Real time computer (AC-100), DEC Vax station, signal conditioning and power amplifiers have been acquired,
  - Developing a test verified dynamic model,
  - Control analysis ongoing using different complexity models,
  - Pointing Sample Problem available.
- Flight experiment progress
  - Awarded In-Step program in spring of 1990.
  - Completed Conceptual Design Review in December 1990.
  - Critical Experiment Support Module elements have been designed (e.g., realtime computer, up/down link, etc.)
  - Testbed hardware and control analysis development satisfy various flight specific requirements.

MULTIBODY TESTBED
(COMPLETION SCHEDULE)

- Testbed
  - Three CSA zero spring rate suspension devices to be installed in late January, 1991.
  - Two axis gimbal to be shipped from LMSC to MIT in late January, 1991.
  - Detailed dynamic model development completed by early February, 1991.
  - Realtime control capability available by mid February, 1991.
  - Testbed operational by end of February 1991.
- Flight experiment
  - Preliminary Design Review in early fall 1991.
  - Critical Design Review in early 1992
  - Launch in spring 1994.

MULTIBODY TESTBED
(RESEARCH ACTIVITIES)

- Influence of gravity and suspension effects on controlled structures.
- Command Input shaping for minimal excitation of residual flexible motion.
- Constrained feedback architecture optimal control.
- Large motion, nonlinear dynamics and control.
- Pointing and scanning control of rigid payloads mounted on a flexible sub-structure.

MODE PROGRAM (RESEARCH ACTIVITIES)

- Gravity effects on structural nonlinearity.
- Describing function approach to structural nonlinearity.
- Component force state mapping.
- Modelling of fluid slosh in arbitrary tank geometries and under different gravity loads.

THE MODE FAMILY OF EXPERIMENTS

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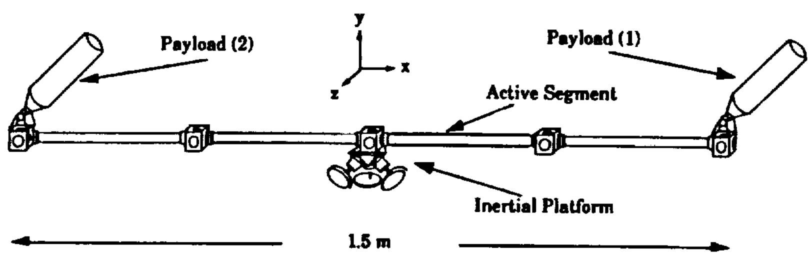

MULTIBODY PLATFORM (PROGRESS IN PAST YEAR)

- Testbed progress

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  Testbed hardware and control analysis development satisfy various flight specific requirements.

Multibody Testbed (Completion Schedule)

- Testbed

  Three CSA zero spring rate suspension devices to be installed in late January, 1991.

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  Realtime control capability available by mid February, 1991.

  Testbed operational by end of February 1991.

- Flight experiment

  Preliminary Design Review in early fall 1991.

  Critical Design Review in early 1992

  Launch in spring 1994.

Multibody Testbed (Research Activities)

- Influence of gravity and suspension effects on controlled structures.
- Command Input shaping for minimal excitation of residual flexible motion.
- Constrained feedback architecture optimal control.
- Large motion, nonlinear dynamics and control.
- Pointing and scanning control of rigid payloads mounted on a flexible sub-structure.

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INTEGRATED TECHNOLOGY PLAN
FOR THE CIVIL SPACE PROGRAM

DEBRIS MAPPING SENSOR TECHNOLOGY PROJECT SUMMARY

TECHNOLOGY FLIGHT EXPERIMENTS PROGRAM AREA
OF THE
SPACE PLATFORMS TECHNOLOGY PROGRAM

JUNE 27, 1991

OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON, DC 20546

SPACE PLATFORMS TECHNOLOGY
TECHNOLOGY FLIGHT EXPERIMENTS

DEBRIS MAPPING SENSOR

OBJECTIVES

PROGRAMMATIC
IMPROVED CHARACTERIZATION OF THE ORBITAL DEBRIS ENVIRONMENT (LEO & GEO). PROVIDE A PASSIVE SENSOR TEST BED FOR DEBRIS COLLISION DETECTION SYSTEMS

TECHNICAL
- LEO DEBRIS ALTITUDE, SIZE AND TEMPERATURE DISTRIBUTION DOWN TO 1 MM PARTICLES
- QUANTIFY GROUND BASED RADAR AND OPTICAL DATA AMBIGUITIES
- OPTIMIZE DEBRIS DETECTION STRATEGIES

SCHEDULE

1994	REFINE SYSTEM DESIGN CONCEPT
1995	BEGIN PHASE C/D
1996	CRITICAL DESIGN REVIEW
1998	DELIVER TO KSC
1999	LAUNCH

RESOURCES*

1994	$2.0 M
1995	$8.1 M
1996	$22.0 M
1997	$20.0 M

PARTICIPANTS

JSC
PROJECT AND TECHNICAL MANAGEMENT, AND ANALYSIS OF SCIENCE DATA.

NASA Lyndon B. Johnson Space Center

DEBRIS COLLISION WARNING SENSOR May 15, 1991	PRINCIPAL INVESTIGATOR: FAITH VILAS PROJECT MANAGER: DON HARRIS

METEOROID AND DEBRIS ENVIRONMENT

- 200 KG OF METEOROID MASS EXIST WITHIN 2000 KM OF EARTH'S SURFACE.
  - — METEOROIDS PASS THROUGH EARTH ORBITAL SPACE.
- 3,000,000 KG OF MAN-MADE OBJECT MASS EXIST WITHIN 2000 KM OF EARTH'S SURFACE.
  - — DEBRIS CAN STAY IN EARTH ORBIT FOR YEARS.
- AVERAGE TOTAL ACCUMULATION RATE (LINEAR) OF LEO DEBRIS HAS BEEN 5% PER YEAR.
- DEBRIS HAZARD IS LARGE ENOUGH TO AFFECT THE SPACE STATION DESIGN:
  - — SURFACE DEGRADATION FROM DEBRIS < .1 MM DIAM.
  - — INCREASED FREQUENCY OF REPAIR OF NON-CRITICAL ELEMENTS FROM DEBRIS 0.1 MM TO 1 CM DIAM.
  - — CRITICAL ELEMENT LOSS FROM DIRECT IMPACT OR INDIRECTLY FROM SECONDARY DEBRIS PIECES CAUSED BY IMPACTS ON OTHER ELEMENTS BY LARGE, NON-TRACKABLE DEBRIS (1 CM TO ~ 30 CM DIAM.)

NASA Lyndon B. Johnson Space Center

DEBRIS COLLISION WARNING SENSOR FEBRUARY 7,1991	PRINCIPAL INVESTIGATOR: FAITH VILAS PROJECT MANAGER: DON HARRIS

UNCERTAINTY IN CURRENT LEO DEBRIS MODEL

- JSC GROUND-BASED OPTICAL OBSERVATIONS SUGGEST 10-30 CM SIZE RANGE DEBRIS POPULATION TRACKED BY U.S. SPACE COMMAND UP TO 75% INCOMPLETE
- RADAR CANNOT DETECT NONMETALLIC DEBRIS
- NO "HARD" DATA IN 1 MM - 10 CM SIZE RANGE
- SIZE OF SMALL DEBRIS ASSUMED FROM RADAR RETURN <u>OR</u> OPTICAL INTENSITY
  - OPTICAL SIZE DATA BASED ON ASSUMED REFLECTANCE PROPERTIES
  - ATMOSPHERIC INTERFERENCE PREVENTS GROUND-BASED IR OBSERVATIONS

NASA Lyndon B. Johnson Space Center

DEBRIS COLLISION WARNING SENSOR May 15, 1991	PRINCIPAL INVESTIGATOR: FAITH VILAS
	PROJECT MANAGER: DON HARRIS

DATA SOURCES FOR THE DEFINITION OF THE LEO DEBRIS ENVIRONMENT ≥ 1MM IN SIZE

- US SPACE COMMAND CATALOG
- RADAR OBSERVATIONS PROGRAM (TEMPORAL LEO MONITORING)
  - —HAYSTACK OBSERVATIONS
    - DETECT OBJECTS ≥ 0.6 CM UP TO 1000 KM OVERHEAD
    - DETECT OBJECTS ≥ 1 CM AT SS ALTITUDE AND LATITUDE
  - —GOLDSTONE OBSERVATIONS
    - DETECT DEBRIS ≥ 2 MM AT SS ALTITUDES
  - —FUTURE RADAR OBSERVATIONS
- GROUND-BASED OPTICAL TELESCOPIC OBSERVATIONS DETECT DEBRIS ≥ 10 CM.
  - —PORTABLE 12" TELESCOPE
  - —GEODSS

NASA Lyndon B. Johnson Space Center

DEBRIS COLLISION WARNING SENSOR May 15, 1991	PRINCIPAL INVESTIGATOR: FAITH VILAS
	PROJECT MANAGER: DON HARRIS

SPACE BASED LEO OBSERVATIONS NECESSARY

- REMOVE LEO ENVIRONMENT MODEL UNCERTAINTY
  - TO 1MM SIZES AT SSF ALTITUDES
  - TO 3 CM SIZES THROUGHOUT LEO
- RESOLVE AMBIGUITY BETWEEN OPTICAL AND RADAR OBSERVATIONS TO ENABLE MORE ACCURATE GROUND OBSERVATION
- REDUCE RISK TO SSF FROM MODEL UNCERTAINTY AT SSF ALTITUDES

SPACE-BASED GEO OBSERVATIONS NECESSARY

- SURVEY RADAR CANNOT REACH GEO ALTITUDES
- EARTH'S ATMOSPHERE LIMITS OPTICAL AND IR GROUND TELESCOPES
- ORBIT-TO-ORBIT OBSERVATIONAL TECHNIQUES WHICH OPTIMIZE GEO OBSERVATIONS CANNOT BE DONE FROM EARTH.

NASA Lyndon B. Johnson Space Center

DEBRIS COLLISION WARNING SENSOR May 15, 1991	PRINCIPAL INVESTIGATOR: FAITH VILAS
	PROJECT MANAGER: DON HARRIS

GEO DEBRIS ENVIRONMENT

- GEO DEBRIS ENVIRONMENT CURRENTLY INADEQUATELY MEASURED - NO GROUND-BASED RADAR OR OPTICAL TELESCOPES CAN DEFINE GEO ENVIRONMENT TO SAME LIMIT AS LEO.
- GEO DEBRIS SOURCES:
  - — INACTIVE PAYLOADS
  - — SPENT UPPER STAGE ROCKET BOOSTERS
  - — SOLID ROCKET PROPELLANT WASTE
  - — OPERATIONAL DEBRIS (E.G. BOLTS, STRAPS, SPIN-UP WEIGHTS, ETC.)
  - — EXPLOSIONS?
  - — BREAK UPS IN GEO TRANSFER ORBITS

NASA Lyndon B. Johnson Space Center

DEBRIS COLLISION WARNING SENSOR
May 15, 1991

PRINCIPAL INVESTIGATOR: FAITH VILAS

PROJECT MANAGER: DON HARRIS

DCWS EXPERIMENT OBJECTIVES

- DETERMINE ALBEDO (% REFLECTIVITY), SPECTRAL CHARACTERISTICS OF LARGE SAMPLE OF LEO AND GEO DEBRIS.
- CORRELATE SPACE-BASED AND GROUND-BASED DEBRIS OBSERVATIONS.
- OBSERVE DEBRIS IN 1 MM - 30 CM DIAMETER RANGE (NOT FULLY DEFINED BY GROUND-BASED OBSERVATIONS)
  - REDUCE MODEL UNCERTAINTY
  - CALIBRATE GROUND/BASED OBSERVATIONS
- DEVELOP AND TEST DETECTOR EFFECTIVENESS FOR SPACE STATION COLLISION DETECTION SYSTEMS.

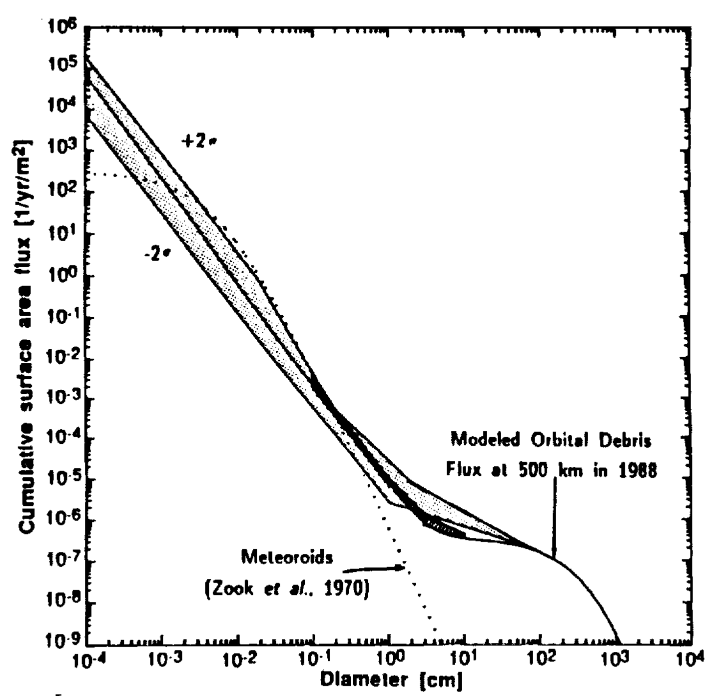
NASA Lyndon B. Johnson Space Center

DEBRIS COLLISION WARNING SENSOR
May 15, 1991

PRINCIPAL INVESTIGATOR: FAITH VILAS

PROJECT MANAGER: DON HARRIS

IMPROVEMENT IN LEO ENVIRONMENT MODEL UNCERTAINTY WITH DCWS DATA



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DEBRIS COLLISION WARNING SENSOR MAY 15,1991	PRINCIPAL INVESTIGATOR: FAITH VILAS PROJECT MANAGER: DON HARRIS

CURRENT STATUS

- BASELINE SCIENCE REQUIREMENTS DOCUMENT
- BASELINE DESIGN CONCEPTS HAVE BEEN ESTABLISHED BY BOTH CONTRACTORS
- PHASE B STUDY RESULTS PRESENTED IN APRIL 1991

  INCLUDING:

  — HARDWARE DEFINITION AND PRELIMINARY OPERATIONS REQUIREMENTS

  — SYSTEM CONCEPTUAL DESIGN AND SPECIFICATIONS

  — EXPERIMENT COST ESTIMATE
- DEVELOPMENT OF INDEPENDENT GOVERNMENT COST AND SCHEDULE ESTIMATES HAS BEEN INITIATED
- PROJECT PLAN DEVELOPMENT IS UNDERWAY